PB87-206074

# Municipal Waste Combustion Study
# Report to Congress

Radian Corp., Research Triangle Park, NC

Prepared for

Environmental Protection Agency, Washington, DC

Jun 87

U.S. Department of Commerce
National Technical Information Service
NTIS

PB87-206074 R

United States
Environmental
Protection Agency

Office of Solid Waste
and Emergency Response
Washington, DC 20460

Office of Air
and Radiation
Washington, DC 20460

Office of Research
and Development
Washington, DC 20460

EPA/530-SW-87-021a
June 1987

EPA

# Municipal Waste Combustion Study

## Report to Congress

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL
INFORMATION SERVICE
SPRINGFIELD, VA 22161

NTIS

50272-101

**REPORT DOCUMENTATION PAGE**

**1. REPORT NO.** EPA/530-SW-87-021A

**2.**

**3. Recipient's Accession No.** PB87-206074/AS

**4. Title and Subtitle**

Municipal Waste Combustion Study: Report to Congress

**5. Report Date** June 1987

**6.**

**7. Author(s)** Stephen Greene

**8. Performing Organization Rept. No.** 232-001-74

**9. Performing Organization Name and Address**

Radian Corporation
P.O. Box 13000
Research Triangle Park, N.C. 27709

**10. Project/Task/Work Unit No.**

**11. Contract(C) or Grant(G) No.**

(C) 68-01-7053
(G)

**12. Sponsoring Organization Name and Address**

Office of Solid Waste and Emergency Response
U.S. Environmental Protection Agency
401 M Street, SW
Washington, D.C. 20460

**13. Type of Report & Period Covered** Final

**14.**

**15. Supplementary Notes**

This report provides an overview of the entire nine-volume Municipal Waste Combustion Study (EPA/530-SW-87-021 A - I).

**16. Abstract (Limit: 200 words)**

This report to Congress is in response to Section 102 of the Hazardous and Solid Waste Amendments (HSWA) of 1984. Section 102 of HSWA requires that the EPA provide a report to Congress describing:

"(i) the current data and information available on emissions of polychlorinated dibenzo-p-dioxins from resource recovery facilities burning municipal solid waste;

(ii) any significant risks to human health posed by these emissions; and

(iii) operating practices appropriate for controlling these emissions."

EPA expanded the scope of the report to cover additional pollutants emitted from municipal waste combustors and all available pollution control techniques. This report provides an overview of the entire municipal waste combustion study. The report discusses the numbers and types of existing and projected facilities; estimates of emissions; options for controlling emissions; risks from emissions and potential for control; costs; and sampling, analysis, and monitoring of emissions.

**17. Document Analysis a. Descriptors**

**b. Identifiers/Open-Ended Terms**

**c. COSATI Field/Group**

**18. Availability Statement** Release Unlimited

**19. Security Class (This Report)** Unclassified

**20. Security Class (This Page)** Unclassified

**21. No. of Pages**

**22. Price**

(See ANSI-Z39.18)

See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

[illegible]7

# MUNICIPAL WASTE COMBUSTION STUDY:

## REPORT TO CONGRESS

Prepared by
Office of Solid Waste and Emergency Response
U.S. Environmental Protection Agency
401 M Street S.W.
Washington, D.C. 20460

## ACKNOWLEDGEMENTS

Many persons contributed to the comprehensive study of municipal waste combustion. Stephen Greene, U.S. EPA, was the EPA's coordinator for the effort. James D. Kilgroe was the coordinator of the EPA's Office of Research and Development activities. Glynda E. Wilkins, Radian Corporation, provided coordination and administrative assistance for the project. Primary authors and contributors include the following:

Municipal Waste Combustion Study: Report to Congress - Stephen Greene (EPA) and Glynda Wilkins (Radian Corporation).

Municipal Waste Combustion Study: Combustion Control of Organic Emissions - James D. Kilgroe (EPA), W.R. Seeker (Energy and Environmental Research Corporation), W.S. Lanier (Energy and Environmental Research Corporation), M.P. Heep (Energy and Environmental Research Corporation).

Municipal Waste Combustion Study: Flue Gas Cleaning Technology - T.G. Brna (EPA) and Charles B. Sedman (EPA).

Municipal Waste Combustion Study: Sampling and Analysis of Municipal Waste Combustors - Larry Johnson (EPA) and Judith Harris (Arthur D. Little).

Municipal Waste Combustion Study: Model Units and Cost of Flue Gas Cleaning Technologies - Mike Johnston (EPA).

Municipal Waste Combustion Study: Assessment of Health Risks Associated with Exposure to Municipal Waste Combustion Emissions - Bob Kellam (EPA), David Cleverly (EPA), Rayburn M. Morrison (EPA), and Larry Fradkin (EPA).

Municipal Waste Combustion Study: Characterization of the Municipal Waste Combustion Industry - Rayburn M. Morrison (EPA), Gary Bockol (Radian Corporation) and Keith Barnett (Radian Corporation).

Municipal Waste Combustion Study: Emission Data Base for Municipal Waste Combustors - Peter Schindler (EPA), Steve Schliesser (Midwest Research Institute), and Dennis Wallace (Midwest Research Institute).

Municipal Waste Combustion Study: Recycling of Solid Waste - David Cleverly (EPA), Karen Fidler (Radian Corporation), and Glynda Wilkins (Radian Corporation).

The EPA's Municipal Waste Combustion Work Group provided an invaluable forum for discussion, review, and direction in completing this study. The review and guidance provided by the Science Advisory Board on portions of the document are also greatly appreciated.

# TABLE OF CONTENTS

Section Page

EXECUTIVE SUMMARY .......... vi

1 INTRODUCTION .......... 1

1.1 PURPOSE .......... 1
1.2 BACKGROUND .......... 2
1.3 SCOPE .......... 4

2 MUNICIPAL WASTE DISPOSAL .......... 6

2.1 LANDFILLING .......... 6
2.2 RECYCLE .......... 7
2.3 COMBUSTION .......... 8

2.3.1 TYPES OF COMBUSTORS .......... 9
2.3.2 DESCRIPTION OF THE INDUSTRY .......... 12

2.3.2.1 DISTRIBUTION OF COMBUSTORS BY TYPE .......... 14
2.3.2.2 DISTRIBUTION OF MUNICIPAL WASTE COMBUSTORS BY LOCATION .......... 20
2.3.2.3 PROJECTIONS THROUGH THE YEAR 2000 .......... 25

3 ENVIRONMENTAL ISSUES .......... 26

3.1 SOLID RESIDUES .......... 26
3.2 EMISSIONS TO THE ATMOSPHERE .......... 27

3.2.1 PARTICULATE MATTER .......... 30
3.2.2 SULFUR DIOXIDE .......... 33
3.2.3 HYDROCHLORIC ACID .......... 35
3.2.4 METALS .......... 37
3.2.5 CDD AND CDF .......... 42

4 OPTIONS FOR CONTROLLING EMISSIONS TO THE ATMOSPHERE .......... 51

4.1 ORGANICS .......... 52

4.1.1 COMBUSTION CONTROLS .......... 57
4.1.2 FLUE GAS TREATMENT .......... 61

4.2 ACID GASES .......... 64
4.3 NITROGEN OXIDES .......... 67
4.4 PARTICULATE MATTER .......... 67
4.5 METALS .......... 68
4.6 MULTIPOLLUTANT CONTROL STRATEGIES .......... 71

## TABLE OF CONTENTS (Continued)

Section | Page

5 IMPACTS OF POTENTIAL CONTROL STRATEGIES.................. 77

5.1 ESTIMATED HEALTH RISK UNDER TWO CONTROL SCENARIOS..... 77

5.1.1 METHODOLOGY.................................. 77

5.1.1.1 EMISSIONS AND CONTROL SCENARIOS......... 78
5.1.1.2 EXPOSURE MODELING...................... 83
5.1.1.3 RISK MEASURES.......................... 84
5.1.1.4 ASSUMPTIONS............................ 85

5.1.2 RISKS FROM DIRECT INHALATION.................. 85

5.1.2.1 RANGES AND UNCERTAINTIES............... 85
5.1.2.2 CANCER RISK............................ 90
5.1.2.3 NON-CARCINOGENIC EFFECTS............... 92

5.1.3 INDIRECT EXPOSURE............................. 93

5.2 ENVIRONMENTAL EFFECTS............................ 94
5.3 POSSIBLE REDUCTIONS IN IMPACTS................... 96
5.4 COSTS............................................ 96
5.5 COST/RISK ANALYSIS............................... 101

6 SAMPLING, ANALYSIS AND MONITORING....................... 104

6.1 SAMPLING......................................... 104
6.2 SAMPLE PREPARATION............................... 109
6.3 ANALYSIS......................................... 109
6.4 MONITORING....................................... 109

7 REFERENCES.............................................. 117

APPENDIX A DOCUMENTS PREPARED BY THE EPA'S ENVIRONMENTAL CRITERIA ASSESSMENT OFFICE........................... A-1

APPENDIX B LISTS OF EXISTING AND PLANNED MUNICIPAL WASTE COMBUSTION FACILITIES............................... B-1

APPENDIX C SUMMARY MATRICES OF EMISSIONS TEST DATA.............. C-1

APPENDIX D MUNICIPAL WASTE COMPOSITION......................... D-1

APPENDIX E EMISSION CONTROL COST TABLES........................ E-1

APPENDIX F SUMMARY OF SYMBOLS, ACRONYMS, AND ABBREVIATIONS....... F-1

APPENDIX G LIST OF CONVERSION FACTORS.......................... G-1

## LIST OF TABLES

Table Page

2-1 SUMMARY OF EXISTING MWC FACILITIES .......... 15

2-2 SUMMARY OF PLANNED MUNICIPAL WASTE COMBUSTION FACILITIES .......... 18

2-3 STATES WITH THE LARGEST EXISTING CAPACITY TO PROCESS MUNICIPAL SOLID WASTE .......... 21

2-4 STATES WITH PLANNED GROWTH IN MUNICIPAL WASTE COMBUSTION CAPACITY EXCEEDING 5000 TONS PER DAY .......... 24

3-1 SUMMARY OF EMISSIONS MEASURED FROM THE THREE MAJOR CLASSES OF MUNICIPAL WASTE COMBUSTORS .......... 29

3-2 MASS BURN FACILITIES FOR WHICH HIGHEST AND LOWEST EMISSION LEVELS WERE MEASURED FOR SELECTED METALS .......... 39

3-3 MODULAR FACILITIES FOR WHICH HIGHEST AND LOWEST EMISSION LEVELS WERE MEASURED FOR SELECTED METALS .......... 41

3-5 SUMMARY OF CDD/CDF EMISSIONS FROM MUNICIPAL WASTE COMBUSTORS .......... 44

3-6 MASS BURN FACILITIES FOR WHICH HIGHEST AND LOWEST STACK GAS CONCENTRATIONS WERE MEASURED FOR SELECTED GROUPS OF CDD AND CDF .......... 47

3-7 MODULAR FACILITIES FOR WHICH HIGHEST AND LOWEST STACK GAS CONCENTRATIONS WERE MEASURED FOR SELECTED GROUPS OF CDD AND CDF .......... 49

4-1 RANK ORDER CORRELATION RESULTS FOR CO vs. CDD/CDF .......... 54

4-2 GOOD COMBUSTION PRACTICES FOR THE MINIMIZATION OF ORGANIC EMISSIONS FROM MUNICIPAL WASTE COMBUSTORS .......... 59

4-3 CONTROL EFFICIENCY DATA FOR CDD .......... 63

4-4 EXPECTED EFFECTIVENESS OF ACID GAS CONTROLS (% REMOVAL). 65

4-5 CONTROL EFFICIENCY DATA FOR ACID GASES .......... 66

4-6 INLET/OUTLET METAL CONCENTRATIONS FROM QUEBEC PILOT PLANT TESTING (ug/Nm$^3$ @ 8% $O_2$) .......... 70

4-7 SUMMARY OF TESTING OF MULTIPOLLUTANT CONTROL STRATEGY AT QUEBEC CITY .......... 73

## LIST OF TABLES (Continued)

Table | Page

4-8 SUMMARY OF TESTING OF MULTIPOLLUTANT CONTROL STRATEGY PERFORMED BY NIRO........................................ 74

4-9 COMPARISON OF PILOT-SCALE TESTS OF MULTIPOLLUTANT CONTROL EQUIPMENT........................................ 75

5-1 METALS EMISSION FACTOR DATA SUMMARY..................... 79

5-2 MUNICIPAL WASTE COMBUSTION FACILITIES FROM WHICH TEST DATA WERE USED FOR ORGANIC EMISSION FACTORS............. 80

5-3 EMISSION CONTROLS ON EXISTING SOURCES................... 82

5-4 ESTIMATED CANCER RISK FROM INHALATION NATIONWIDE (BASELINE CONTROL SCENARIO.............................. 86

5-5 ESTIMATED CANCER RISK FROM INHALATION NATIONWIDE (CONTROLLED SCENARIO)................................. 87

5-6 CONTRIBUTION OF CDD/CDF TO TOTAL ANNUAL INCIDENCE ESTIMATES.................................................. 88

5-7 PROJECTED AMBIENT HCl CONCENTRATIONS CONTRIBUTED BY MUNICIPAL WASTE COMBUSTORS.............................. 95

5-8 POSSIBLE REDUCTIONS OF HEALTH RISK AND HCl CONCENTRATIONS FROM DIRECT EMISSION PATHWAYS........................... 97

5-9 INCREMENTAL COST/RISK COMPARISON........................ 103

6-1 STACK (FLUE GAS) SAMPLING METHODS....................... 106

6-2 SUMMARY OF SAMPLE PREPARATION METHODS................... 110

6-3 ANALYSIS METHODS FOR TRACE ORGANICS AND TRACE METALS, APPLICABLE TO MUNICIPAL WASTE COMBUSTOR SAMPLES......... 112

6-4 CONTINUOUS MONITORING DEVICES FOR MUNICIPAL WASTE COMBUSTORS................................................ 114

## LIST OF FIGURES

Figure Page

2-1 Diagram of a Modern Mass Burn Facility.................. 10

2-2 Modular Combustor....................................... 11

2-3 Diagrams of RDF Processing and Combustion............... 13

2-4 Distribution of Existing Installed Municipal Waste Combustion Capacity by Design Type..................... 16

2-5 Distribution of Planned Municipal Waste Combustion Capacity by Design Type................................ 19

2-6 Regional Distribution of Existing Municipal Waste Combustion Facilities................................. 22

2-7 Regional Distribution of Planned Municipal Waste Combustion Facilities................................. 23

3-1 Summary of CDD Stack Gas Emissions Test Data............ 45

3-2 Summary of CDF Stack Gas Emissions Test Data............ 46

4-1 Comparison of CDD/CDF Stack Gas Concentrations to CO Stack Gas Concentrations.............................. 53

4-2 Summary of Theories for CDD/CDF Municipal Waste Combustor Stack Gas.................................... 55

5-1 Annualized Operating Cost Estimates for Model Mass Burning Facilities...................................... 100

5-2 Annualized Operating Cost Estimates for Model Modular Combustor Facilities.................................. 100

5-3 Annualized Operating Cost Estimates for Model Refuse-Derived Fuel Burning Facilities......................... 100

# EXECUTIVE SUMMARY

## INTRODUCTION

This report to Congress is in response to Section 102 of the Hazardous and Solid Waste Amendments (HSWA) of 1984. Section 102 of HSWA requires that the EPA provide a report to Congress describing:

"(i) the current data and information available on emissions of polychlorinated dibenzo-p-dioxins from resource recovery facilities burning municipal solid waste;

(ii) any significant risks to human health posed by these emissions; and

(iii) operating practices appropriate for controlling these emissions."

The EPA has enlarged the scope of the Section 102 report to include additional information generated during an integrated study of Municipal Waste Combustion. The integrated study resulted in this Report to Congress and eight technical reports. Much of the information contained in this report has been extracted from the technical reports.

## MUNICIPAL WASTE COMBUSTION IN THE UNITED STATES

Combustion of municipal waste is an attractive waste management option because it reduces the volume of the waste by 70 to 90 percent. In the face of shrinking landfill availability, municipal waste combustion capacity in the United States is expected to grow rapidly, from the current U.S. capacity of 45,000 tons per day to 117,000 to 252,000 tons per day by the year 2000. This added capacity is expected to be added with nearly 200 new municipal waste combustion facilities.

There are currently 111 municipal waste combustion facilities in the United States. Figure 1 shows their geographic distribution. Figure 2 shows geographic locations of 210 facilities known by the EPA to be planned or under construction. The maps show that municipal waste combustion facilities are concentrated on the East Coast with many facilities also planned for California.

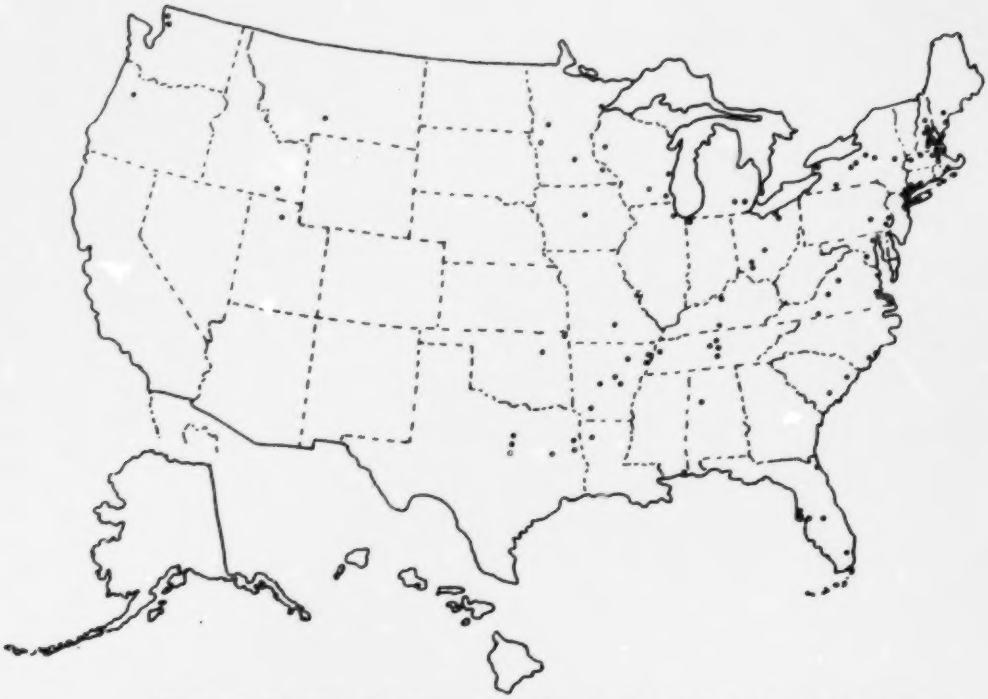


Figure 1. Regional Distribution of Existing Municipal Waste Combustion Facilities

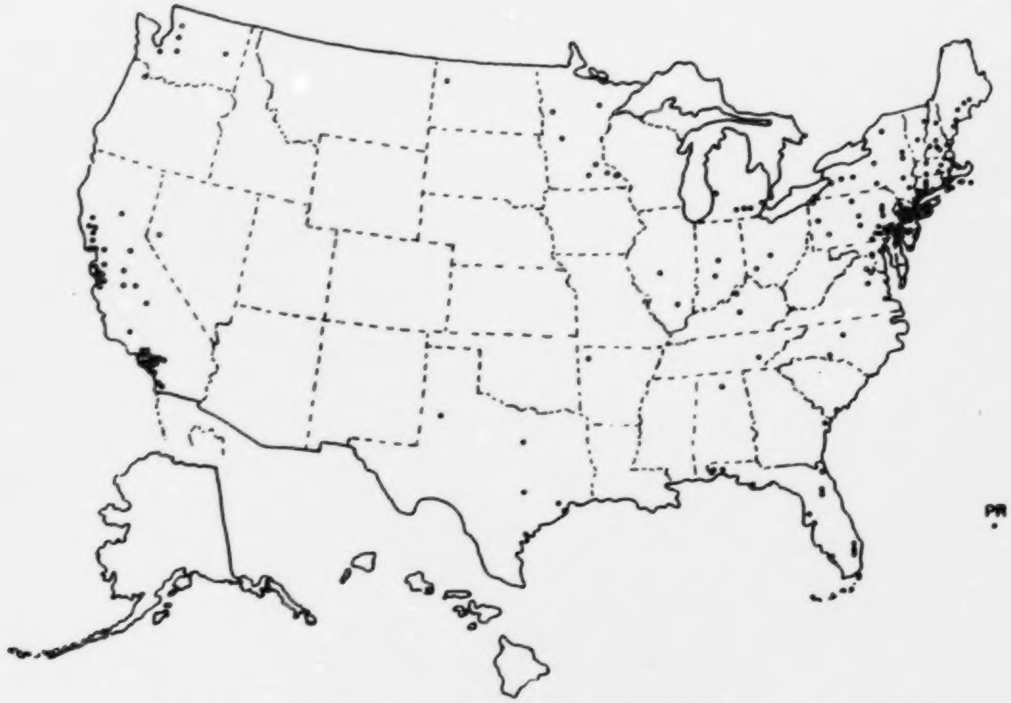
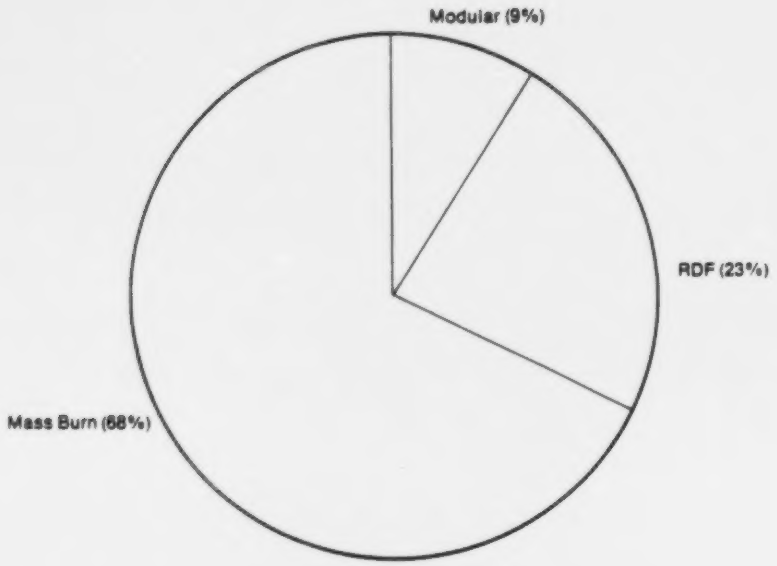


Figure 2. Regional Distribution of Planned Municipal Waste Combustion Facilities

Three main types of combustors are used for combustion of municipal waste: mass burn, modular, and those that fire refuse-derived fuel (RDF). The first type is called "mass burn" because the waste is combusted without any pre-processing other than removal of items too large to go through the feed system. In a typical mass burn combustor, refuse is placed on a grate that moves through the combustor. Combustion air in excess of stoichiometric amounts is supplied both below (underfire air) and above (overfire air) grate. Mass burn combustors are usually field-erected and range in size from 50 to 1000 tons per day of refuse throughput per unit. Many mass burn facilities have 2 or more combustors and have site capacities of greater than 1000 tons per day.

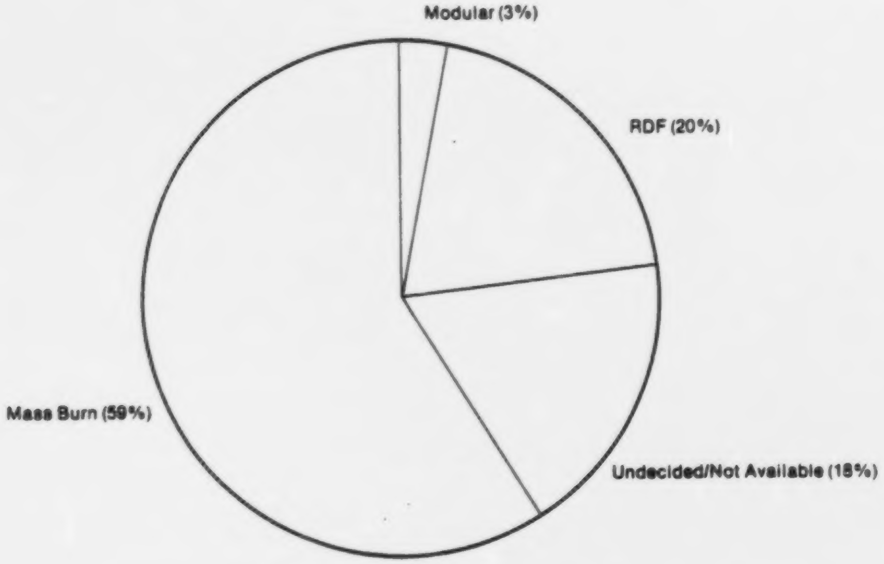
Modular combustors also burn waste without pre-processing, but they are typically shop fabricated and generally range in size from 5 to 100 tons per day of refuse throughput. One of the most common types of modular combustors in the starved air or controlled air type, incorporating two combustion chambers. Air is supplied to the primary chamber at substoichiometric levels. The incomplete combustion products pass into the secondary combustion chamber where excess air is added and combustion is completed. Another type of modular combustor, functionally similar to larger, mass burn units, uses excess air in the primary chamber; no additional air is added in the secondary chamber. The third major type burns refuse-derived fuel (RDF). This type of combustor burns processed waste which may vary from shredded waste to finely divided fuel suitable for co-firing with pulverized coal.

The distribution of the existing U.S. waste combustion capacity among the three types is shown in Figure 3. As shown, mass burn facilities have the largest share of U.S. capacity, 68 percent of the total. RDF facilities represent 23 percent of the total capacity, and modular facilities account for 9 percent. Although modular facilities represent a small fraction of the total U.S. capacity, the number of facilities equipped with modular facilities is greater than the number of combustion facilities equipped with mass burn units (56 modular facilities compared to 45 mass burn facilities). There are ten RDF facilities in operation.



Total Design Capacity = 49,000 tons per day

Figure 3. Distribution of Existing Installed Municipal Waste Combustion Capacity by Design Type



Total Design Capacity = 190,000 tons per day

Figure 4. Distribution of Planned Municipal Waste Combustion Capacity by Design Type

Figure 4 shows the expected distribution of design types for planned facilities the EPA has knowledge of. Mass burn facilities are expected to continue to dominate with 59 percent of the U.S. design capacity. RDF facilities are expected to account for 20 percent, and design capacity for modular facilities is expected to account for 3 percent.

## EMISSIONS AND THEIR CONTROL

Environmental concerns have been raised about both solid residues and pollutants emitted to the air from municipal waste combustors. Particular concern has been raised concerning the presence of chlorinated dibenzo-p-dioxins (CDD) and chlorinated dibenzofurans (CDF) in emissions to the air and solid residues.

The EPA is currently working to determine the most environmentally acceptable methods for disposal of municipal waste combustor solid residues. The Agency's findings concerning residue disposal will be published when that work is complete. The remainder of this Report to Congress and the accompanying technical reports focus on environmental effects of emissions to the air from municipal waste combustors.

As part of the integrated study, EPA attempted to collect all available data on emissions from municipal waste combustors. From this data the EPA established an emissions data base of almost 50 facilities from which emissions had been measured in documented tests. Comparison of the data from different tests is difficult because the facilities vary widely in design and operating conditions, the tests were conducted with different objectives and different protocols, and the level of detail of the reported data varies. Further, the specific sampling and analysis methods were not the same for all tests. These differences make it difficult not only to make comparisons among the combustors tested, but also to draw conclusions about the entire population of combustors. Nevertheless, this study has used these data to the extent possible to evaluate municipal waste combustion practices.

Pollutants of interest emitted from municipal waste combustors include metals, acid gases (primarily HCl), organics (including CDD and CDF), and, in some localities, $NO_x$, as well. Table 1 contains a summary of emissions quantities measured from municipal waste combustors.

For municipal waste combustors controlling emissions involves controlling emissions of a whole list of pollutants. Moreover, application of control technology for one pollutant or class of pollutants may affect control of other pollutants. Devising a control strategy, then, involves consideration of control techniques for each of the classes of pollutants present but also requires consideration of the effects of a selected control technique on the entire list.

Options for control include optimization for minimizing organic emissions; scrubbing for acid gas control; flue gas cooling for condensation of metals and organics; high efficiency particulate matter collection; and $NO_x$ control where necessary. A control approach designed to incorporate all of these processes, thereby minimizing emissions of the whole list of pollutants would be:

- optimization of the combustion process,
- alkaline scrubbing combined with ESPs or fabric filters operated at temperatures conducive to promoting condensation, and
- flue gas treatment for $NO_x$ control, if necessary.

Some of the newest facilities in Europe and in the United States have incorporated the first two parts of this approach, and at least one facility in California has incorporated all three parts. The alkaline scrubbers being chosen for most of the new facilities are dry scrubbers.

With a goal of optimizing combustion in mind the EPA developed a set of combustion strategy elements termed "good combustion practices," summarized in Table 2. Also shown are preliminary specifications for each of the elements. Even though these good combustion practices are preliminary and have not been verified in field tests, they have been included because it is important for permit writers and those applying for permits to be aware of the conditions that promote achievement of complete combustion.

TABLE 1. SUMMARY OF EMISSIONS MEASURED FROM THE THREE MAJOR CLASSES OF MUNICIPAL WASTE COMBUSTORS[a]

| Pollutant | Mass Burn | Modular | RDF-Fired |
|---|---|---|---|
| Particulate matter | 5.5 - 1,530 mg/Nm$^3$<br>(0.002 - 0.669 gr/dscf) | 23 - 300 mg/Nm$^3$<br>(0.012 - 0.13 gr/dscf) | 220 - 530 mg/Nm$^3$<br>(0.096 - 0.230 gr/dscf) |
| Sulfur dioxide | 0.04 - 401 ppmdv | 61 - 124 ppmdv | 55 - 188 ppmdv |
| Nitrogen oxides | 39 - 380 ppmdv | 260-310 ppmdv | 263 ppmdv[b] |
| Carbon monoxide | 18.5 - 1,350 ppmdv | 3.2 - 67 ppmdv | 217 - 430 ppmdv |
| Hydrogen chloride | 7.5 - 477 ppmdv | 160 - 1270 ppmdv | 96 - 780 ppmdv |
| Hydrogen fluoride | 0.62 - 7.2 ppmdv | 1.1 - 16 ppmdv | 2.1 ug/Nm$^3$ [b] |
| Arsenic | 0.452 - 233 ug/Nm$^3$ | 6.1 - 119 ug/Nm$^3$ | 19 - 160 ug/Nm$^3$ |
| Beryllium | 0.0005 - 0.33 ug/Nm$^3$ | 0.096 - 0.11 ug/Nm$^3$ | 21 ug/Nm$^3$ [b] |
| Cadmium | 6.2 - 500 ug/Nm$^3$ | 21 - 942 ug/Nm$^3$ | 34 - 370 ug/Nm$^3$ |
| Chromium | 21 - 1,020 ug/Nm$^3$ | 3.6 - 390 ug/Nm$^3$ | 490 - 6,700 ug/Nm$^3$ |
| Lead | 25 - 15,000 ug/Nm$^3$ | 237 - 15,500 ug/Nm$^3$ | 970 - 9,600 ug/Nm$^3$ |
| Mercury | 9 - 2,200 ug/Nm$^3$ | 130 - 705 ug/Nm$^3$ | 170 - 440 ug/Nm$^3$ |
| Nickel | 230 - 480 ug/Nm$^3$ | <1.92 - 553 ug/Nm$^3$ | 130 - 3,600 ug/Nm$^3$ |
| TCDD | 0.20 - 1,200 ng/Nm$^3$ | 1.0 - 43.7 ng/Nm$^3$ | 3.5 - 260 ng/Nm$^3$ |
| TCDF | 0.32 - 4,600 ng/Nm$^3$ | 12.2 - 345 ng/Nm$^3$ | 32 - 680 ng/Nm$^3$ |
| PCDD | 1.1 - 11,000 ng/Nm$^3$ | 63 - 1540 ng/Nm$^3$ | 54 - 2,840 ng/Nm$^3$ |
| PCDF | 0.423 - 15,000 ng/Nm$^3$ | 97 - 1810 ng/Nm$^3$ | 135 - 9,100 ng/Nm$^3$ |

[a] See Appendix C for summary of facilities represented in emissions data for each pollutant category. Results summarized are from full scale commercial facilities only.

[b] Only one test.

TABLE 2. GOOD COMBUSTION PRACTICES FOR THE MINIMIZATION OF ORGANIC EMISSIONS FROM MUNICIPAL WASTE COMBUSTORS

| Practice | Mass Burn Preliminary Target | RDF Preliminary Target | Starved-air Preliminary Target |
|---|---|---|---|
| Design temperature at fully mixed height | 1800°F at fully mixed height | 1800°F at fully mixed height | 1800°F at fully mixed height |
| Underfire air control | At least four separately adjustable plenums. One each under the drying and burnout zones and at least two separately adjustable plenums under the burning zone. | As required to provide uniform bed burning stoichiometry | |
| Overfire air capacity (not an operating requirement) | 40% of total air | 40% of total air | 80% of total air |
| Overfire air injector design | That required for penetration and coverage of furnace cross-section | That required for penetration and coverage of furnace cross-section | That required for penetration and coverage of furnace cross-section |
| Auxiliary fuel capacity | That required to meet start-up temperature and 1800°F criteria under part-load operations | That required to meet start-up temperature and 1800°F criteria under part-load operations | That required to meet start-up temperature and 1800°F criteria under part-load conditions |
| Excess Air | 6 - 12% excess oxygen (dry basis) | 3 - 9% excess oxygen (dry basis) | 6 - 12% excess oxygen (dry basis) |
| Turndown restrictions | 80 - 110% of design - lower limit may be extended with verification tests | 80 - 110% of design - lower limit may be extended with verification tests | 80 - 110% of design - lower limit may be extended with verification tests |
| Start-up procedures | On auxiliary fuel to design temperature | On auxiliary fuel to design temperature | On auxiliary fuel to design temperature |
| Use of auxiliary fuel | On prolonged high CO or low furnace temperature | On prolonged high CO or low furnace temperature | On prolonged high CO or low furnace temperature |
| Oxygen in flue gas (continuous monitor) | 6 - 12% dry | 3 - 9% dry | 6 - 12% dry |
| CO in flue gas (continuous monitor) | 50 ppm on 4 hour average - corrected to 12% $CO_2$ | 50 ppm on 4 hour average - corrected to 12% $CO_2$ | 50 ppm on 4 hour average - corrected to 12% $CO_2$ |
| Furnace temperature (continuous monitor) | Minimum of 1800°F (mean) at fully mixed height across furnace | Minimum of 1800°F (mean) at fully mixed height | Minimum of 1800°F (mean) at fully mixed plane (secondary chamber) |
| Adequate air distribution | Verification test* | Verification test* | Verification test* |

*See text in Section 4 and "Municipal Waste Combustion Study: Combustion Control of Organic Emissions," Chapter 9.

Recent test data obtained from a new municipal waste combustor in Tulsa show that low concentrations of organics may be achieved by optimizing combustion conditions. Moreover, emissions testing has recently begun on municipal waste combustors equipped with dry scrubbers combined with particulate matter collection devices. Recently collected test data show generally high removal efficiencies for all pollutants except mercury, and even for mercury one set of pilot plant test data show higher control efficiencies may be possible with sufficient cooling.

## HEALTH RISK ANALYSIS

The EPA performed a health risk analysis of two control scenarios. One, the baseline scenario, approximates the status quo in control technology, mostly particulate matter emission control. The second reflects uniform application of dry alkaline scrubbing combined with particulate matter collection devices. Estimated health risk under these two control scenarios was generated for both the existing population of combustors and for those facilities planned for construction.

Two different expressions of health risk were generated: aggregate annual incidence and maximum individual risk. Aggregate annual incidence values include the total number of cancer cases per year predicted by the models in populations living within 50 kilometers of all the municipal waste combustors in the United States. Maximum individual risk values are the model's estimates of the probability that a person exposed to the highest modeled concentration of pollutants from a municipal waste combustor will develop cancer due to continuous exposure over a 70-year lifetime.

The EPA's risk analysis estimated direct inhalation cancer risks associated with maintaining the status quo in control technology for the existing facilities and those projected for the near future. Most of the estimated cancer risk is attributable to chlorinated dibenzo-para-dioxins (CDD) and chlorinated dibenzofurans (CDF). There remain basic questions concerning the mechanism of carcinogenesis for these and related compounds. The models used to estimate the plausible, upper bound carcinogenic potency of compounds such as CDD/CDF, implicitly assume that the substance acts directly to initiate cancer. If, however, CDD/CDF acts as a promoting agent, as some scientists believe, to amplify the carcinogenic response of other direct acting carcinogens, the present model may not be appropriate. A change of this nature in the assumption on which the cancer potency estimate is based could lead to a reduction in this estimate.

The ranges presented below reflect uncertainties regarding the relative toxicity of structurally related compounds, and the ability to accurately measure compounds at trace levels. These estimates also reflect assumptions including a conservative extrapolation of the results of epidemiological and animal studies, mathematical modeling of pollutant dispersion, constant emission rates based on those at tested facilities, and constant exposure of persons to pollutants for 70 years.

The estimates of annual incidence aggregated over the United States and for all pollutants modeled are 3 to 38 cases per year for the existing combustors and 2-22 for those projected. Estimated maximum individual risks (As noted above, these are for the greatest potential exposure.) range from 1/1000 to 1/10,000 for existing facilities and from 1/10,000 to 1/100,000 for those projected to be built in the next few years. Uniform application of dry scrubbers combined with high efficiency particulate collection devices would be expected to reduce annual incidence to 0.2 to 3 cases for existing sources, and 0.3 to 1 for those projected. Similarly, such controls would reduce maximum individual risks to 1/10,000 to 1/100,000 for existing facilities and 1/100,000 to 1/1,000,000 for projected facilities.

When the risk estimates are disaggregated by design type, the component contributed by mass burn technology used in existing facilities dominates the risk contributed by the major design types. However, the risk component contributed by RDF technology dominates in the projected facilities.

A preliminary analysis was performed to determine whether indirect exposure routes due to surface deposition of pollutants from municipal waste combustors could contribute significantly to total exposure due to municipal waste combustors. The analysis was designed to evaluate the combination of parameters that would result in the maximum exposure that was still within the realm of plausibility. Results showed that for mercury and lead indirect exposure may be a significant part of the total exposure due to municipal waste. However, no such indications were seen for nickel, chromium, or formaldehyde. Also, the modeling results showed that indirect exposure to environmentally persistent organic compounds may be comparable to the direct inhalation route of exposure. Analysis of indirect exposure as a possible source of health risk is continuing.

## COST OF CONTROL

The incremental cost of adding dry scrubbing to particulate matter control (considered representative of the status quo) at municipal waste combustors is $4 to $9 per ton of garbage combusted at mass burn units and $4 to $5 per ton for RDF-fired combustors. The same increment for modular combustors is $5 to $12 per ton of garbage combusted. However, many existing modular units are equipped with no flue gas treatment devices, so the cost for those units would be higher, about $7 to $16 per ton.

# 1. INTRODUCTION

## 1.1 PURPOSE

This Report to Congress is in response to Section 102 of the Hazardous and Solid Waste Amendments (HSWA) of 1984. Section 102 of HSWA requires that the EPA provide a report to Congress describing:

"(i) the current data and information available on emissions of polychlorinated dibenzo-p-dioxins from resource recovery facilities burning municipal solid waste;

(ii) any significant risks to human health posed by these emissions; and

(iii) operating practices appropriate for controlling these emissions."

The request from Congress was specific in its scope, relating only to emissions of polychlorinated dibenzo-p-dioxins from municipal waste combustors. However, the EPA had been investigating numerous other aspects of municipal waste combustion, and these other topics appeared appropriate to include, so the Agency has enlarged the scope of the Section 102 report. This report summarizes the information developed during the integrated study undertaken by the EPA to address the issues raised by Congress. It includes discussions of the following topics:

- equipment used for municipal waste combustion
- emissions and waste streams from municipal waste combustors
- air pollution control techniques
- cost of controls
- estimates of health risk from predicted exposure to pollutants.

Additional information on these and related topics may be found in the following technical documents, also issued as part of the integrated study:

- Municipal Waste Combustion Study: Emissions Data Base for Municipal Waste Combustors (EPA/530-SW-87-021b)
- Municipal Waste Combustion Study: Combustion Control of Organic Emissions (EPA/530-SW-87-021c)
- Municipal Waste Combustion Study: Flue Gas Cleaning Technology (EPA/530-SW-87-021d)

- Municipal Waste Combustion Study: Costs of Flue Gas Cleaning Technologies (EPA/530-SW-87-021e)
- Municipal Waste Combustion Study: Sampling and Analysis (EPA/530-SW-87-021f)
- Municipal Waste Combustion Study: Assessment of Health Risks Associated with Exposure to Municipal Waste Combustion Emissions (EPA/530-SW-87-021g)
- Municipal Waste Combustion Study: Characterization of the Municipal Waste Combustion Industry (EPA/530-SW-87-021h)
- Municipal Waste Combustion Study: Recycling of Solid Waste (EPA/530-SW-87-021i)

Much of the information in this Report to Congress has been extracted from these volumes.

## 1.2 BACKGROUND

Several incidents of environmental contamination by 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD), coupled with the realization of its potential toxicity and persistence, have resulted in a high level of public awareness and concern over potential exposure of human populations to 2,3,7,8-TCDD and other chlorinated dibenzodioxins (CDD). The most notable incidents include the exposure of U. S. servicemen to Agent Orange contaminated with TCDD, the industrial accident in Seveso, Italy, and the contamination of Times Beach, Missouri.

Low levels of CDD and CDF (chlorinated dibenzofurans) are found throughout the environment. Municipal waste combustors emit CDD and CDF to the atmosphere, thereby contributing to environmental levels, but it is difficult to characterize their contribution to the levels found. Municipal waste combustors are not the only known sources from which CDD and CDF enter the environment, nor is the atmosphere the only known route of exposure. Other sources of environmental contamination include the production of chlorinated phenols, a chemical process which produces 2,3,7,8-TCDD as a byproduct. Trace quantities of the byproduct are then carried with the chlorinated phenols into products such as wood preservatives and pesticides.

CDD and CDF from production, use and disposal of these materials may enter the environment, for example, through soil, sediment, or fish.

Atmospheric emissions of CDD and CDF have been measured in stack gases from combustion processes other than municipal waste incinerators, e.g., hazardous waste incinerators, wire reclamation incinerators, secondary copper smelters, wood-fired boilers, sewage sludge incinerators, hospital incinerators, and drum and barrel furnaces. Some recent studies have implicated sources in addition to those listed above, particularly automotive exhaust, in contributing to the levels of CDD and CDF found in urban air and in human tissue.[1,2,3]

Concern over municipal waste combustion as a source of CDD emissions surfaced in 1977 when workers in the Netherlands first reported detection of CDD and CDF in flue gas and fly ash from municipal waste combustors in that country. Very soon after the initial report, CDD and CDF were reported in the 100 ppb range in fly ash from a municipal waste combustor in Switzerland. By 1980, investigators elsewhere in Europe had also reported findings of CDD and CDF in emissions and wastes from municipal waste combustors.[4] In the U.S., emission testing at Hempstead, New York, in 1979 showed CDD and CDF being emitted to the air from the combustor stack. At that time analytical methods were not developed to the extent they are today and only semi-quantitative analysis was possible. However, the detection of CDD and CDF was reinforced by European reports of CDD and CDF measured in municipal waste combustor stack gases and the research published in 1978 by Dow Chemical U.S.A.[5] showing trace quantities of CDD and CDF associated with numerous combustion sources.

In 1984, at the request of Congress, the EPA initiated an investigation of potential contamination of the environment by 2,3,7,8-TCDD. The National Dioxin Strategy was developed and implemented. It included provisions for investigative, remedial, and regulatory activities and evaluated seven types or "tiers" of sources having decreasing expectation of environmental contamination.

One part of the study, "Tier 4" focussed on combustion sources, including municipal waste combustors. Because some testing of municipal waste combustors previously had been performed, only limited testing of those sources was performed under Tier 4 activities. Tier 4 activities were, instead, directed toward sources that had not been widely tested. However, relying on testing previously done or planned, the Agency included emissions of CDD and CDF from municipal waste combustors in its considerations. The Tier 4 study showed that some municipal waste combustors are relatively large emission sources. The results showed wide variability suggesting that it is possible to design and operate municipal waste combustors with relatively low CDD and CDF emissions.

During the implementation of the National Dioxin Strategy, Congress enacted the HSWA of 1984 which included the Section 102 requirement for a report about dioxin emissions from municipal waste combustors.

## 1.3 SCOPE

Several classes of substances are represented by the substances known or generally thought to be present in emissions and waste streams from municipal waste combustors. Classes of chemical substances frequently discussed include metals, organics, CDD and CDF, acid gases, and particulate matter. Some of the substances within these classes have been evaluated for toxicity by the EPA; some have been designated criteria pollutants; and some have been listed as hazardous air pollutants. Other substances present generally are thought or suspected to exhibit toxic health effects in some concentrations but have not been evaluated or listed as toxic or hazardous by the EPA.

The various substances discussed in this report are called simply "pollutants." No judgment is made or implied about their toxicity or hazard potential, except in the section on risk where such issues are addressed in detail. Further information about the health effects of these pollutants can be found in a series of documents issued by EPA's Environmental Criteria Assessment Office. A list of these documents is included in Appendix A.

Nomenclature and acronyms representing some of the organic compounds considered in this report have not been standardized and can be confusing. Chlorinated dibenzo-para-dioxins (CDD) and chlorinated dibenzofurans (CDF) form two families of related compounds. Individual compounds within the families differ in their degree of chlorination and in the placement of their chlorine atoms. Homologs have the same degree of chlorination, i.e., the same number of chlorine atoms, but the chlorine atoms are not necessarily found in the same substitution positions on the molecule. For example, tetra chlorinated dibenzo-p-dioxins include all isomers of chlorinated dibenzo-p-dioxins having four chlorine atoms on the molecular ring structure. Isomers have a particular chlorine atom placement specified. For example, 2,3,7,8-tetrachloro dibenzo-p-dioxin has chlorine atoms in the positions on the molecular ring structure designated by the numbers 2,3,7,and 8.

To avoid having to spell out such long chemical names repeatedly, acronyms and symbols representing classes, homologs, and isomers have been developed. In this report the following naming conventions have been adopted:

CDD - refers to family of chlorinated dibenzo-para-dioxins. PCDD is also used; it stands for polychlorinated dibenzo-para-dioxins.

CDF - refers to family of chlorinated dibenzofurans. PCDF is also used. It stands for polychlorinated dibenzofurans.

TCDD - refers to the homolog group of tetrachlorodibenzo-p-dioxins.

TCDF - refers to the homolog group of tetrachlorodibenzofurans.

Other homolog groups are represented by spelling out the prefix designating the number of chlorine atoms per molecule; e.g., penta-CDD means pentachlorodibenzo-para-dioxin.

# 2. MUNICIPAL WASTE DISPOSAL

Although the emphasis of this report is municipal waste combustion, questions concerning environmental effects are raised in the context of the larger questions concerning environmentally sound municipal waste management practices. Municipal waste is generated in the United States at an ever increasing rate and is expected to grow from a generation rate of 130 to 160 million tons* per year in 1980 to 160 to 290 million tons per year in the year 2000.[6] At present, municipal waste management options are limited to direct landfilling of refuse, recovery and recycle of discarded materials, and combustion of refuse combined with land disposal of residues. The three options are not exclusive. For example, recycling removes materials from refuse, but not all refuse can be recycled, so some portion remains to be landfilled or combusted. Also, combustion is accompanied by ash and bulky items that must be disposed of in landfills.

## 2.1 LANDFILLING

Direct landfilling has been and currently remains the predominant waste management option, accounting for about 85 percent by weight of the waste collected.[6] About 5 percent of the waste collected in the United States was combusted in 1984 and only about 10 percent was recovered for recycle.[7]

Though landfilling currently predominates as the method of municipal waste disposal, it is becoming less attractive. As a result of increased recognition of the environmental damage associated with some landfills, state governments have begun to close some of them. For example, the state of New Jersey has closed over 58 percent of its landfills since 1977 as a result of their reaching design capacity or because of environmental enforcement actions, and only one new landfill has since opened in that state.[8] New York

---

*One ton is equal to 0.9 megagrams. The units used in this report are mixed, metric and English. The use of mixed units arises from usage in the industry. For example, in the United States throughput capacity is traditionally spoken of in English units, while emissions data are quoted in metric units.

City has closed 14 of its 17 landfills over the past 20 years;[9] and California, New Jersey, and Florida have all initiated programs to minimize landfilling as a waste management strategy.

Environmental regulations governing acceptable landfill design and operation are becoming increasingly stringent at the State level, requiring such measures as double liners, leachate containment and monitoring. Federal standards for landfills are currently being reviewed and may be strengthened. Costs for landfill units consistent with new standards could range as high as $45 to $150 per ton of refuse disposed[10] compared to costs from survey data of about $10 to $20 per ton for current landfills.[11] This increased expense is coupled with an ever worsening shortage of landfill space and the increasing quantities of refuse already described. The landfill space shortage is becoming acute in the populous northeastern part of the United States.

The closing of existing sites, the scarcity of new landfill sites, and increased landfill operating costs, combined with the increased quantities of waste are causing waste management strategies to place more emphasis on recycling and combustion. Use of these two options can reduce the volume of waste to be disposed of, thereby extending the life of available landfill sites.

## 2.2 RECYCLE

Renewed interest in recovery of discarded materials for recycle or reuse has been seen across the United States, but particularly in the Northeast where suitable landfill space is scarce. Most of the materials recovery in the United States is accomplished through source separation, that is, manual separation by the generator rather than separation from mixed refuse in centralized waste processing facilities. Thousands of source separation programs are in operation across the United States including 400 to 500 curbside recycling programs. Some states, particularly in the Northeast, have made participation mandatory.[12] Added to the source separation programs, there are some 30 to 40 centralized waste processing plants[13] separating materials from mixed refuse. These plants are producing refuse-derived fuels (RDF). One of the steps in producing RDF is removing non-combustibles from the waste.

Centralized processing methods are becoming increasingly sophisticated and effective at separating waste materials. A notable state-of-the-art system operating in Europe and in South America, the Sorain-Cecchini process, is an integrated recovery system that can produce paper pulp, animal feed, compost, aluminum scrap, ferrous scrap, densified refuse-derived fuel, and pelletized polyethylene for production of sheet plastic used in garbage bags. Plans are currently being made for building a similar system, the ORFA process, in the United States.[14]

Methods for separation and uses for recovered materials have been established for paper, glass, scrap ferrous metals, aluminum, wood waste, yard waste, and rubber. Also, separation methods and markets for recovered plastics are currently the subject of rapidly advancing research. At the present time, technical and economic factors combine to make paper and aluminum the most extensively recycled materials from U.S. waste.

Recycling, while it is not expected to eliminate the interest in combustion, is being considered more frequently as a means to achieve additional volume reduction above and beyond volume reductions achievable using combustion.

## 2.3 COMBUSTION

Combustion of municipal waste is an attractive waste management option because it reduces the volume of the waste by 70 to 90 percent. In the face of shrinking landfill availability, municipal waste combustion capacity in the United States is expected to grow at an astonishing rate, significantly faster than the growth rate for municipal refuse generation. From the current combined U.S. capacity of 45,000 tons per day, combustion capacity has been projected to reach 117,000 to 252,000 tons per day by the year 2000.[6] This added capacity is expected to be achieved with the addition of nearly 200 new facilities.[6]

Modern municipal solid waste combustors are not merely "garbage burners." They are sophisticated boilers that use waste as a fuel. A significant reduction in waste volume in conjunction with the conversion of chemical energy to a useable form, such as steam or electricity, is an attractive option for many municipalities. For these reasons many municipalities are now considering waste-to-energy projects.

### 2.3.1 Types of Combustors

There are three main classes of facilities used to combust municipal refuse: mass burn, modular, and RDF-fired facilities. A fourth class, employing fluidized bed combustors, is not yet common and has not been covered in detail in this study. While these are the main classes, there are variations within the three main classes and there are some examples of designs that incorporate features of more than one class. The first class is called "mass burn" because the waste is combusted without any pre-processing other than removal of items too large to go through the feed system. A diagram of a mass burn furnace is shown in Figure 2-1. In a typical mass burn combustor refuse is loaded from the storage pit to the feed chute. Hydraulic rams or pusher grate sections are used to push the refuse from the fuel chute onto a grate. Grates may be traveling, rocking, or reciprocating, but they are all similar in that they are designed to move waste through the combustor and to promote complete combustion by agitation of the thick fuel bed. (One type of mass burn unit that has no grate at all is a rotary combustor.) Combustion air, supplied to the primary chamber in excess of the stoichiometric amount is introduced both below (underfire air) and above (overfire air) the grate. Most large, new mass burn combustors are expected to have waterwall furnaces for energy recovery. Many older facilities have refractory-lined walls. Ash generated in the combustion process falls into an ash pit from which it is sent to a landfill. Fly ash entrained by the flue gas is collected in a particulate matter collection device before the flue gas enters the stack for discharge to the atmosphere.

Mass burn combustors are field-erected and generally range in size from 50 to 1000 tons per day of refuse feed per unit. Many mass burn facilities have 2 or more combustors and have site capacities of greater than 1000 tons per day.

Modular combustors also burn waste without pre-processing, but they are typically shop-fabricated and range in size from 5 to 100 tons per day of refuse feed per unit. One of the most common modular combustor designs, the Consumat system, is shown in Figure 2-2. In a modular combustor like the one shown in Figure 2-2 the primary chamber is fed using a hopper and ram feed system. Air is supplied to the primary chamber at substoichiometric levels. This results in a lower air velocity in the primary combustion chamber than if

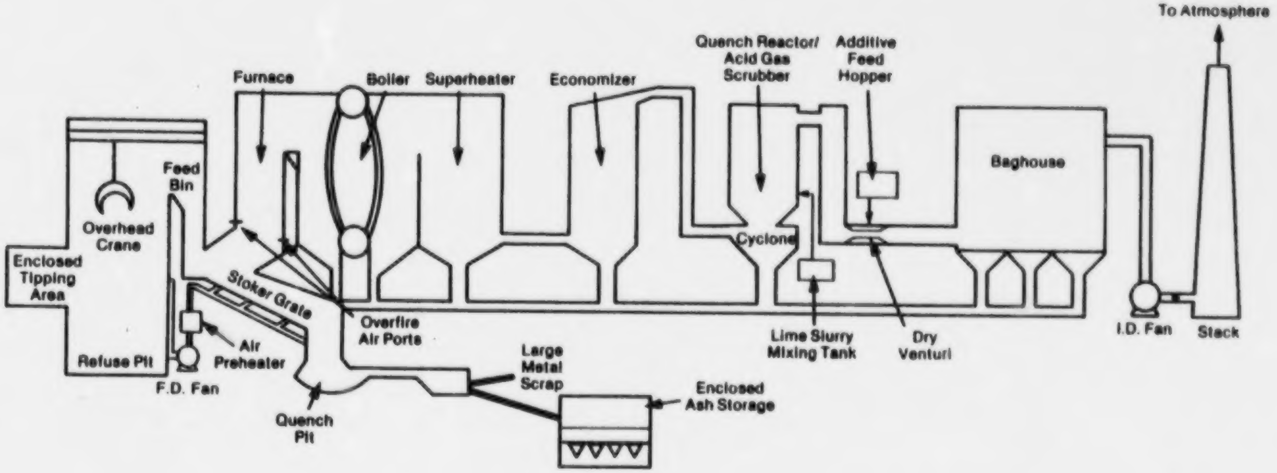
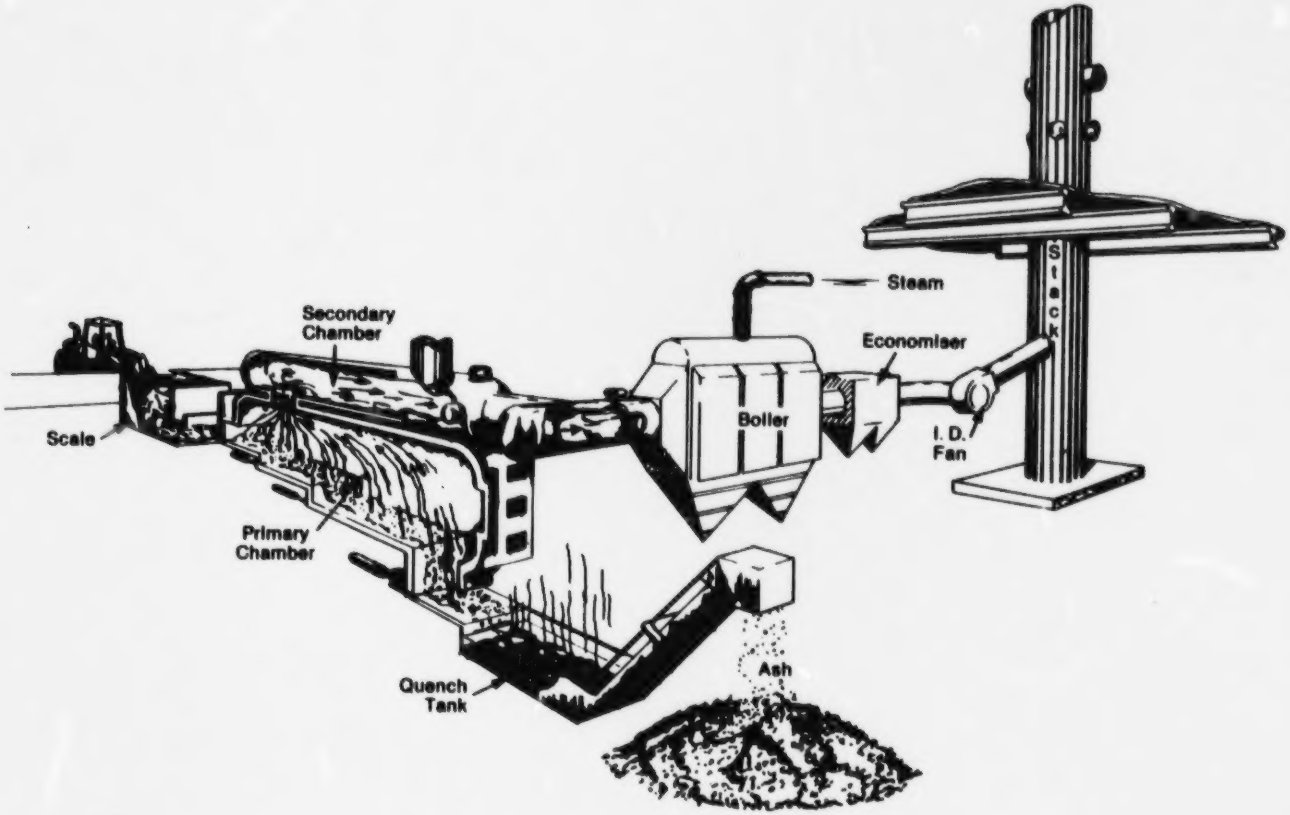

To Atmosphere
Furnace
Boiler
Superheater
Economizer
Quench Reactor/ Acid Gas Scrubber
Additive Feed Hopper
Baghouse
Feed Bin
Overhead Crane
Enclosed Tipping Area
Refuse Pit
Stoker Grate
Cyclone
Air Preheater
F.D. Fan
Overfire Air Ports
Large Metal Scrap
Quench Pit
Enclosed Ash Storage
Lime Slurry Mixing Tank
Dry Venturi
I.D. Fan
Stack

Figure 2 - 1. Diagram of a Modern Mass Burn Facility

4870115R


Secondary Chamber
Steam
Economiser
Stack
Scale
Boiler
I. D. Fan
Primary Chamber
Ash
Quench Tank

Reproduced from best available copy.

Figure 2-2. Modular Combustor[15]
(Reprinted with Permission of Environment Canada)

excess air were used and minimizes entrainment of fuel particles and ash in the flue gas. The incomplete combustion products pass into the secondary combustion chamber where excess air is added and combustion is completed. The auxiliary burner is fired if the secondary chamber temperature falls below a specified level. The resulting hot gases can be passed through a heat recovery boiler for energy recovery. Although several existing modular combustors do not have heat recovery, almost all new and planned modular combustors are expected to incorporate heat recovery.

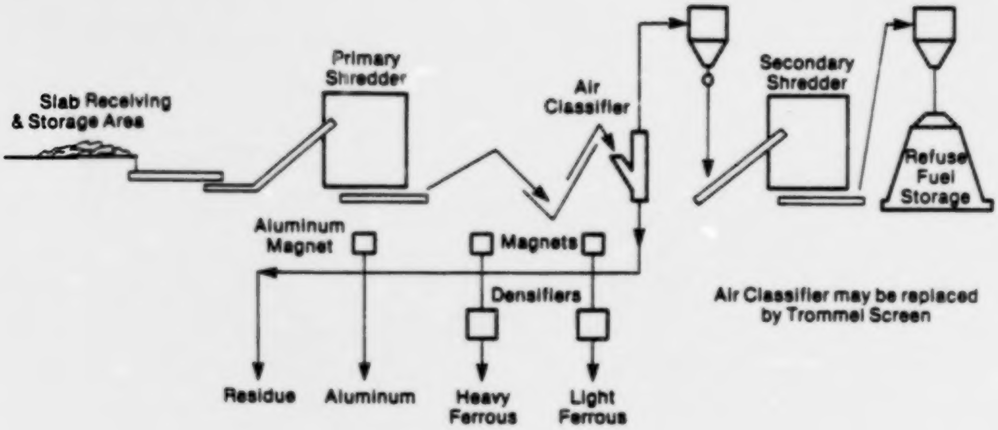
The modular unit described above typically is called a controlled air or starved air combustor. Another type of modular combustor uses excess air in the primary chamber, and no additional air is added in the secondary chamber. In this design the secondary chamber simply provides additional residence time for the completion of combustion. This type of design is functionally similar to larger, mass burn units.

A third major class of municipal waste combustor burns refuse-derived fuel (RDF). Figure 2-3 shows an RDF facility. The types of boilers used to combust RDF can include suspension, stoker, and fluidized bed designs. RDF may be co-fired with a fossil fuel (usually coal), but co-firing is not prevalent and information generated during this study does not include information about co-firing.

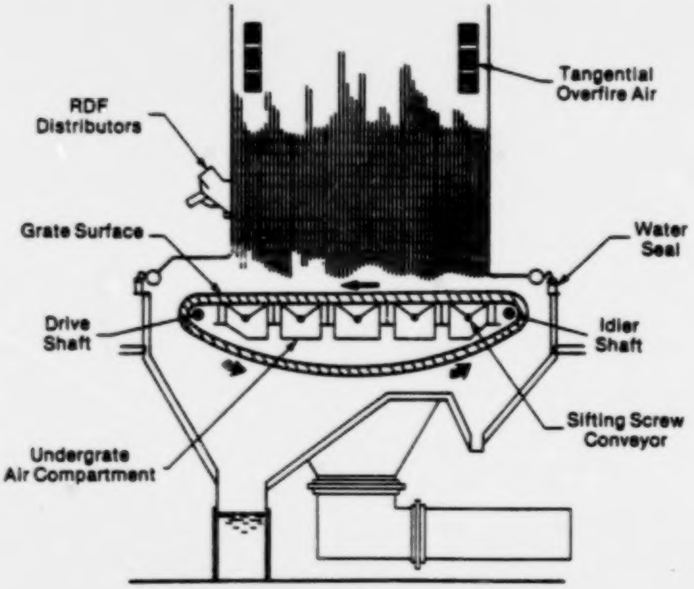
The degree of processing of refuse to yield RDF can vary from simple removal of bulky items accompanied by shredding to extensive processing to produce finely divided fuel suitable for co-firing in pulverized coal-fired boilers. Processed municipal waste, regardless of the degree of processing performed, is broadly referred to as RDF.

### 2.3.2 Description of the Industry

The population of municipal waste combustors in the United States (both existing and projected) is described in terms of 1) throughput or capacity, 2) number of facilities or combustor sites, 3) type of combustor, and 4) location of facilities. Throughput or capacity may be aggregated in several ways: by type of combustor, by number of facilities in a state or region of the United States, or by facility or unit. A facility may consist of one or more combustors. Capacity refers to the amount of municipal waste a facility, unit, or group of facilities is designed to combust.


Slab Receiving
& Storage Area
Primary
Shredder
Air
Classifier
Secondary
Shredder
Refuse
Fuel
Storage
Aluminum
Magnet
Magnets
Densifiers
Residue
Aluminum
Heavy
Ferrous
Light
Ferrous
Air Classifier may be replaced
by Trommel Screen

RDF Combustion


Tangential
Overfire Air
RDF
Distributors
Grate Surface
Water
Seal
Drive
Shaft
Idler
Shaft
Sifting Screw
Conveyor
Undergrate
Air Compartment

2870004RTP

Figure 2-3. Diagrams of RDF Processing and Combustion

In this report, the existing and planned combustor populations will be described first by type, then by location. In both descriptions, distributions of the population are presented by number of facilities and by capacity.

2.3.2.1 Distribution of combustors by type.* There are 111 municipal waste combustion facilities currently in operation in the United States. Table 2-1 presents a summary of these existing facilities. They are grouped by three design types: mass burn, modular, and facilities that produce and combust RDF. These design types were previously described in Section 2.3.1.

The total design capacity for the 111 existing municipal waste combustion facilities is approximately 49,000 tons per day of municipal waste input. Table 2-1 and Figure 2-4 show the distribution of total U.S. capacity among the three design types. Figure 2-4 shows that the mass burn facilities have the largest share of the installed U.S. capacity, 68 percent of the total. The RDF facilities represent 23 percent of the total capacity, and modular represent 9 percent. Though they represent a small amount of the total installed capacity, the number of facilities using modular combustors to combust municipal waste is greater than the number of mass burn facilities (56 facilities with modular combustors compared to 45 mass burn facilities). There are only ten RDF facilities in operation.

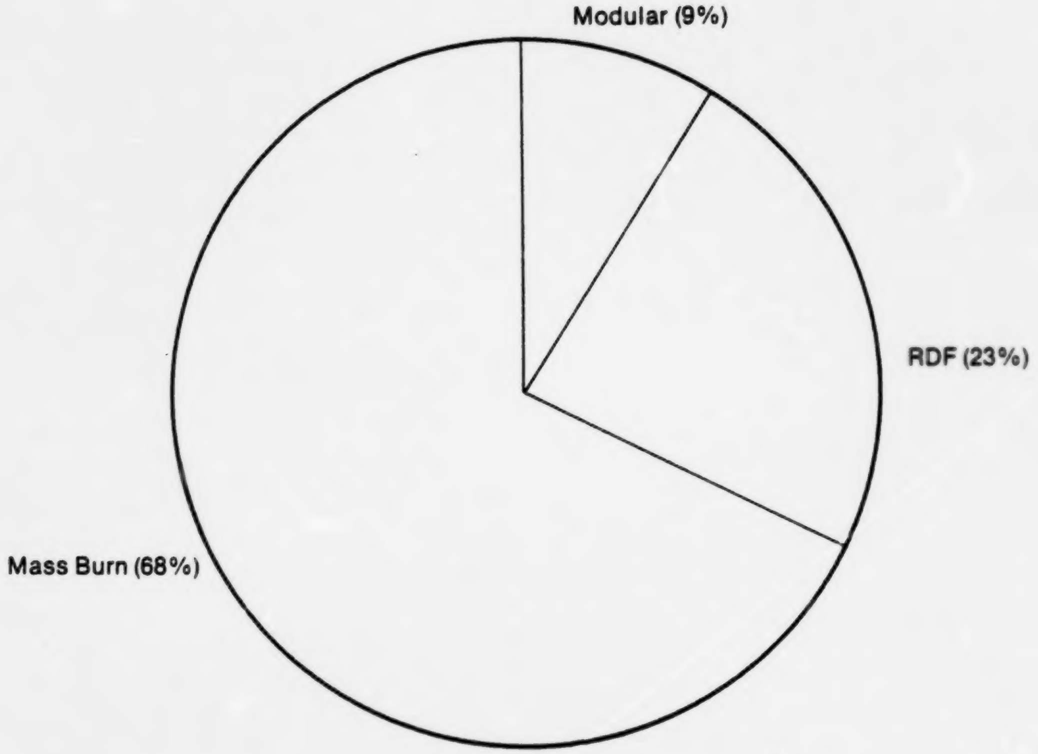
Table 2-1 also shows the size distribution of municipal waste combustion facilities in the U.S. The majority of the facilities with modular combustors (54 of the 56 facilities) have design capacities of less than 250 tons per day. There is no typical design capacity for the mass burn facility. The data indicate that mass burn facilities are designed to meet a variety of capacity requirements, unlike the modular units which are specifically designed for a smaller combustion demand. Twelve mass burn facilities have design capacities less than 250 tons per day, 6 facilities have capacities in

---

*The information in this section is a summary of information presented in Reference 6, Municipal Waste Combustion Study: Characterization of the Municipal Waste Combustion Industry.

## TABLE 2-1. SUMMARY OF EXISTING MWC FACILITIES

| Design Type | Capacity Range (tons per day) | Number of Installed Facilities: With Heat Recovery | Number of Installed Facilities: Without Heat Recovery | Total Installed Capacity (tons per day): With Heat Recovery | Total Installed Capacity (tons per day): Without Heat Recovery |
|---|---|---|---|---|---|
| Mass Burn | <250 | 8 | 4 | 1,291 | 748 |
| Modular | | 37 | 17 | 3,292 | 610 |
| RDF | | 1 | 0 | 200 | 0 |
| Mass Burn | 250 to <500 | 4 | 2 | 1,820 | 900 |
| Modular | | 2 | 0 | 570 | 0 |
| RDF | | 3 | 0 | 1,100 | 0 |
| Mass Burn | 500 to <1000 | 4 | 11 | 2,740 | 7,150 |
| Modular | | 0 | 0 | 0 | 0 |
| RDF | | 1 | 0 | 600 | 0 |
| Mass Burn | ≥1000 | 8 | 4 | 14,250 | 4,200 |
| Modular | | 0 | 0 | 0 | 0 |
| RDF | | 5 | 0 | 9,500 | 0 |
| Totals | | 73 | 38 | 35,363 | 13,608 |
| | | 111 | | 48,971 | |



Total Design Capacity = 49,000 tons per day

4870138R

Figure 2 - 4. Distribution of Existing Installed Municipal Waste Combustion Capacity by Design Type

the 250 to 500 tons per day size range, 15 facilities have capacities in the 500 to 1000 size range, and 12 facilities have capacities equal to or greater than 1000 tons per day. Five of the ten RDF facilities are designed to process more than 1000 tons per day of municipal waste.

Of the 111 existing municipal waste combustion facilities, 73 are designed with heat recovery boilers. Thirty-nine of the 56 facilities with modular combustors (70 percent) and all of the RDF facilities (53 percent) are designed with heat recovery boilers. Heat recovery boilers are prevalent at facilities with modular combustors, because many of these facilities have been built more recently than mass burn facilities, and heat recovery boilers are an integral part of newer designs.

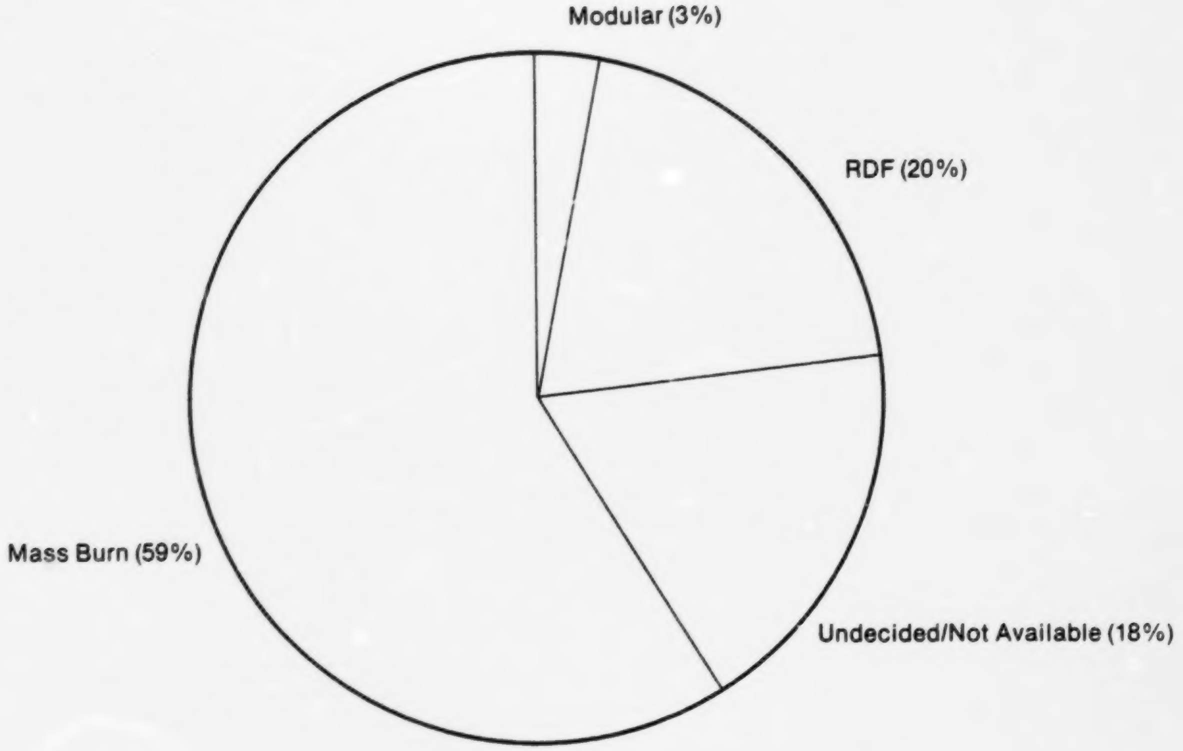
The EPA has information concerning 210 planned municipal waste combustion facilities. Planned facilities are those which are not yet operating, but are either under construction, planned for construction, under negotiation, or have been formally proposed. Table 2-2 presents a summary of these planned facilities. They are grouped by the same design types that were used to group the existing facilities. One hundred and eighteen of the 210 identified planned facilities are mass burn facilities, 24 are facilities planning to install modular combustors, and 31 are RDF facilities. For 37 facilities, data on the design type were either unavailable, or a design type had not been chosen. The total design capacity for the 210 facilities is projected to be approximately 190,000 tons per day, or approximately four times the total design capacity of existing municipal waste combustion facilities. Some of these planned units are in the early stages of planning. Not all of the planned projects will proceed to completion. On the other hand additional new municipal waste combustion projects are being considered every day. The ultimate capacity expected to come on line is obviously uncertain.

Figure 2-5 shows, for planned facilities, the expected distribution of total U.S. capacity among the three primary design types. The mass burn facilities are expected to account for 59 percent of the total design capacity. The RDF facilities are expected to account for 20 percent, and facilities planning to install modular combustors are expected to account for only 3 percent. The remaining 18 percent of planned capacity includes facilities where the design technology is either undecided or not available. All of the planned facilities are expected to incorporate energy recovery.

TABLE 2-2. SUMMARY OF PLANNED MUNICIPAL WASTE COMBUSTION FACILITIES

| Design Type[a] | Design Capacity Range (tons per day) | Number of Planned Facilities | Total Planned Capacity (tons per day) |
|---|---|---|---|
| Mass Burn | <250 | 18 | 3,055 |
| Modular | | 14 | 1,377 |
| RDF | | 3 | 450 |
| DNA | | 7 | 1,225 |
| Mass Burn | 250 to <500 | 17 | 6,155 |
| Modular | | 10 | 3,730 |
| RDF | | 2 | 730 |
| DNA | | 9 | 3,220 |
| Mass Burn | 500 to <1000 | 33 | 21,653 |
| Modular | | 0 | 0 |
| RDF | | 11 | 8,544 |
| DNA | | 6 | 3,700 |
| Mass Burn | ≥1000 | 50 | 82,532 |
| Modular | | 0 | 0 |
| RDF | | 15 | 29,150 |
| DNA | | 15 | 27,850 |
| Totals | | 210 | 193,371 |

[a] DNA indicates that data on design type are not available or the technology is undetermined at this time.



Total Design Capacity = 190,000 tons per day

4870137R

Figure 2 - 5. Distribution of Planned Municipal Waste Combustion Capacity by Design Type

Table 2-2 shows the expected size distribution among planned facilities. Fourteen of the 24 facilities with modular combustors are planned with capacities of less than 250 tons per day. The remaining ten facilities planning modular combustors are expected to fall into the 250 to 500 tons per day capacity size range. Fifty of the 118 mass burn facilities are planned with capacities equal to or greater than 1000 tons per day. Fifteen of the 31 RDF facilities are planned with a capacity equal to or greater than 1000 tons per day.

2.3.2.2 Distribution of Municipal Waste Combustors by Location.* Table 2-3 lists the states with the largest existing capacity to combust municipal waste. New York State has the largest existing capacity with approximately 9,000 tons per day (at 12 facilities). The 6 states listed in Table 2-3 account for a combined capacity of 32,000 tons per day, or nearly 66 percent of the total capacity in the United States. The remaining 29 states and the District of Columbia account for a combined capacity of nearly 17,000 tons per day, or 34 percent of the total capacity. Figure 2-6 shows the geographic distribution of municipal waste combustion facilities in the United States. The figure shows that municipal waste combustion facilities are concentrated on the east coast. A complete list of existing municipal waste combustion facilities is included in Appendix B.

Table 2-4 lists the States with the planned growth in municipal waste combustion of greater than 5000 tons per day capacity. California's planned growth in combustion capacity of approximately 43,000 tons per day (at 36 facilities) is the largest. The 9 states listed in Table 2-4 account for a combined planned capacity of approximately 150,000 tons per day, or nearly 80 percent of the planned capacity in the United States. The remaining 34 states account for a combined planned capacity of nearly 40,000 tons per day, or 20 percent of the total planned capacity for the United States. Figure 2-7 shows the distribution of planned municipal waste combustion facilities in the

---

*The information presented in this section is a summary of information presented in Reference 2, Municipal Waste Combustion Study: Characterization of the Municipal Waste Combustion Industry.

TABLE 2-3. STATES WITH THE LARGEST EXISTING CAPACITY TO PROCESS MUNICIPAL SOLID WASTE

| State | Number of Facilities | Existing Capacity (tons per day)[a] |
|---|---|---|
| New York | 12 | 9,025 |
| Florida | 5 | 7,498 |
| Massachusetts | 6 | 5,640 |
| Ohio | 5 | 4,400 |
| Maryland | 2 | 3,450 |
| Pennsylvania | 3 | 2,220 |
| Subtotal | 33 | 32,233 |
| Remaining States[b] | 78 | 16,738 |
| Total | 111 | 48,971 |

[a] Ranked in descending order by capacity.

[b] Each of the remaining States has a total existing capacity less than 2000 tons per day. New Hampshire has 12 modular facilities with a total capacity of 517 tons per day.

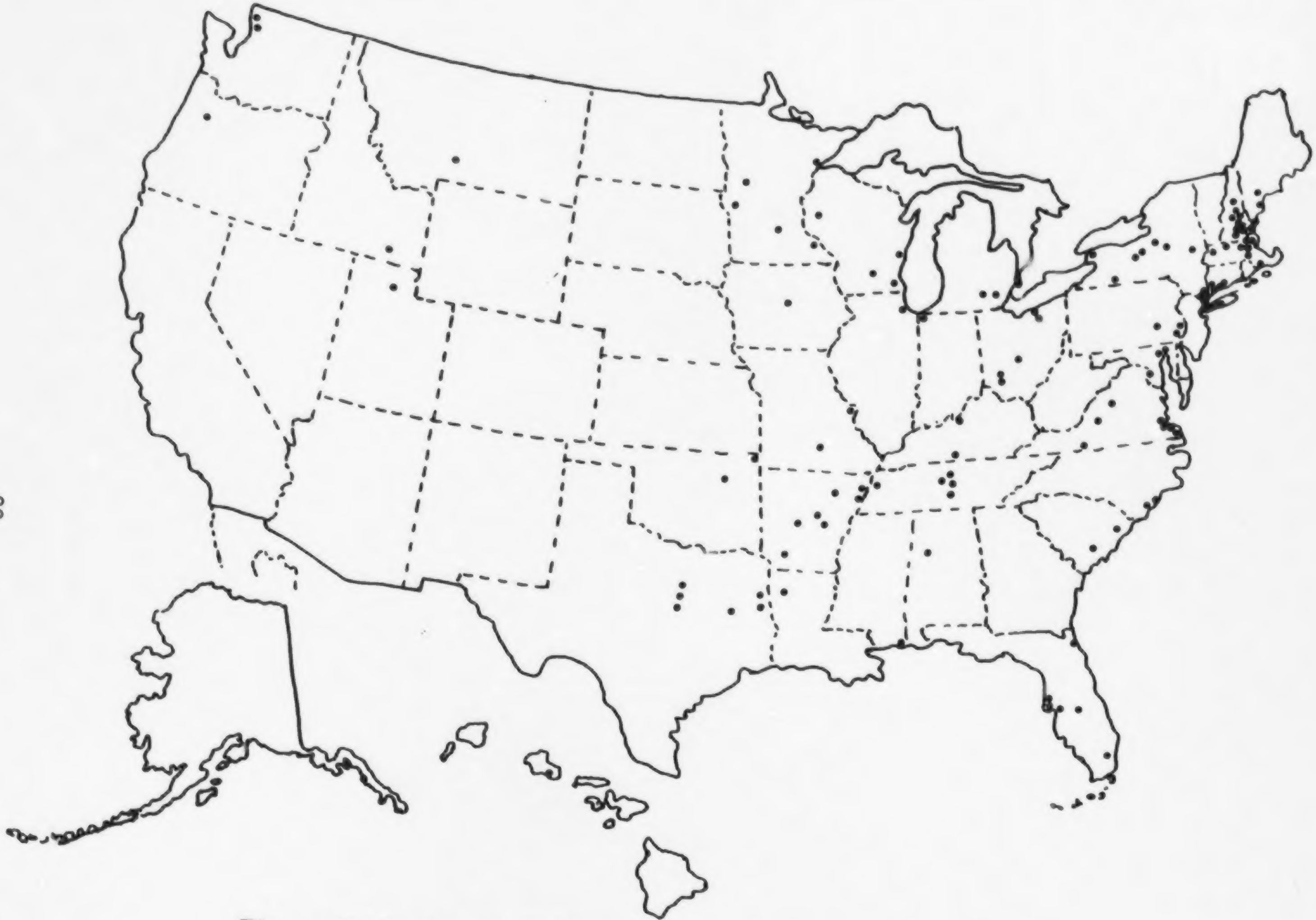


Figure 2 - 6. Regional Distribution of Existing Municipal Waste Combustion Facilities

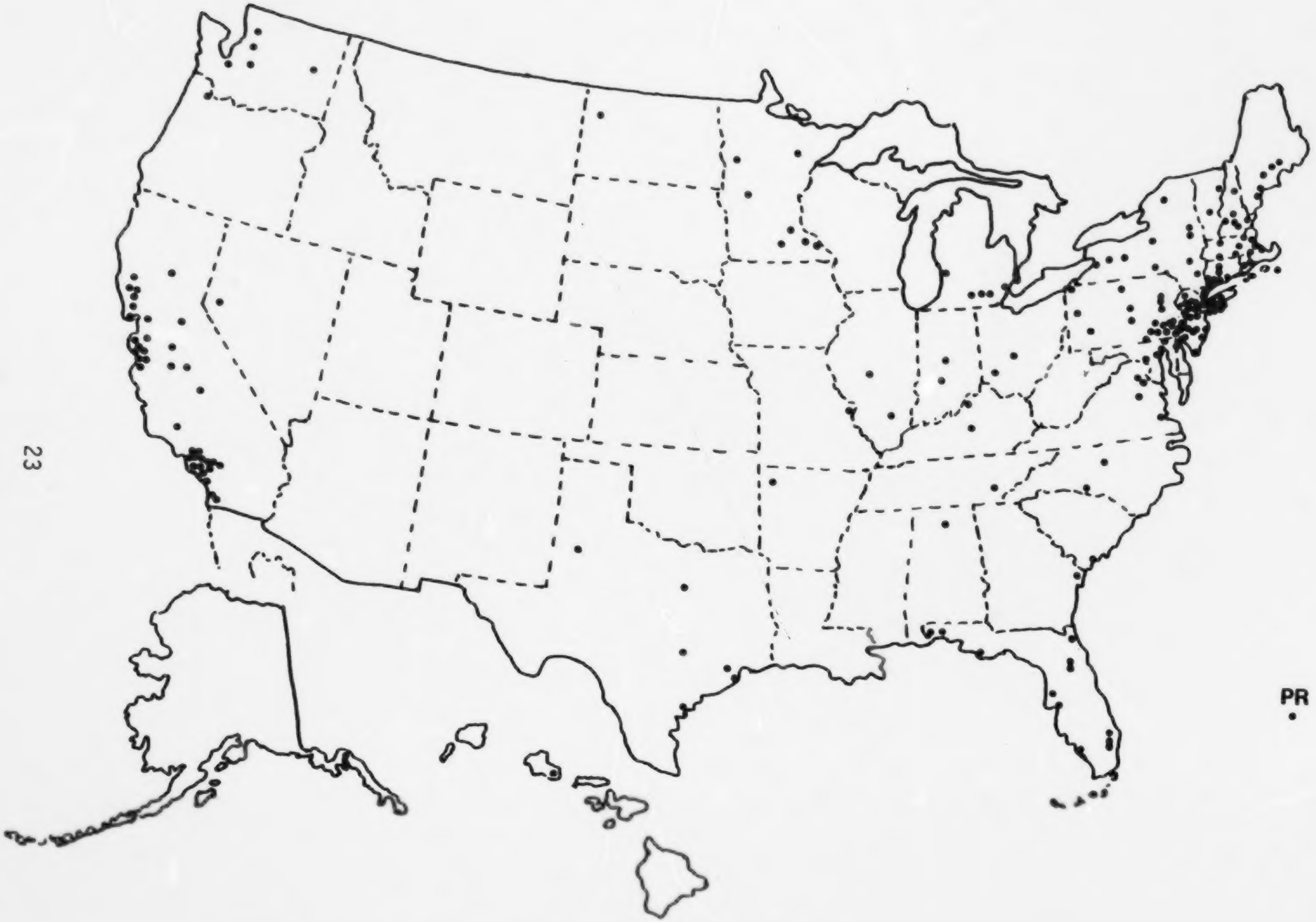


Figure 2-7. Regional Distribution of Planned Municipal Waste Combustion Facilities

## TABLE 2-4. STATES WITH PLANNED GROWTH IN MWC CAPACITY EXCEEDING 5000 TONS PER DAY[a]

| State | Number of Facilities | Planned Capacity (Tons Per Day) |
|---|---|---|
| California | 36 | 42,522 |
| New York | 23 | 22,853 |
| New Jersey | 6 | 23,955 |
| Pennsylvania | 26 | 18,472 |
| Florida | 13 | 14,420 |
| Massachusetts | 11 | 10,060 |
| Connecticut | 11 | 8,520 |
| Virginia | 4 | 8,375 |
| Washington | 5 | 5,150 |
| Subtotal | 149 | 154,327 |
| Remaining States | 61 | 39,044 |
| Total | 210 | 193,371 |

[a] Ranked in descending order by capacity.

United States. The figure shows increasing activity in municipal waste combustion on both the east and west coasts. A list of planned municipal waste combustion facilities known to the EPA is shown in Appendix B.

2.3.2.3 Projections through the Year 2000.* Most of the facilities identified by EPA as planned will be constructed by 1990 if there are not serious delays in implementation. The EPA has also made projections of the growth of the municipal waste combustion industry through the year 2000. These projections are largely based on market surveys and projections in the increase in the generation of municipal waste.

Market analysis from several sources indicates substantial growth in the total number and capacity of facilities out to the year 2000; although, the extent of the growth predicted varies with the different analyses. Estimates indicate that over 300 facilities will be on-line and operating by that time. The total projected capacity is expected to be between 113,000 and 260,000 tons per day by the year 2000.

Based on the capacities of existing and planned facilities, mass burn facilities are expected to account for between 60 and 70 percent of the total projected capacity by the year 2000. Facilities that combust RDF will constitute between 20 and 30 percent, and facilities with modular combustors will account for approximately 10 percent of the total projected capacity by the year 2000.

The net growth in the number of municipal waste combustors by the year 2000 is dependent on the growth in the number of new facilities minus the closing of existing facilities. The EPA estimates that the number of existing facilities to be retired or closed over the next 15 years will be small in number. This projection results from the fact that the majority of existing municipal waste combustors were built since 1970 and, therefore, will have less than 30 years in operation by the year 2000. Some refurbishing of facilities currently shut down may also occur, adding to the projected capacity.

---

*The information in this section is a summary of information presented in Reference 6, Municipal Waste Combustion Study: Characterization of the Municipal Waste Combustion Industry.

# 3. ENVIRONMENTAL ISSUES

Converging with the shift in waste management strategies and the resultant growth in municipal waste combustor population is rising concern about the environmental effects of municipal waste combustion. Environmental concern has been raised about solid residues as well as pollutants emitted to the atmosphere. Particular concern exists, as mentioned previously, with the confirmation of the presence of CDD and CDF in emissions and residues.

## 3.1 SOLID RESIDUES

The Resource Conservation and Recovery Act applies to disposal of the bottom ash and collected fly ash from municipal waste combustion facilities. These residues generally contain metals such as lead and cadmium.

EPA has reviewed data from the literature concerning results of EP toxicity tests (as described in 40 CFR 261.24) on ash. The Agency has no information to indicate the reliability of these data. A majority of the fly ash tests reported indicate levels of lead or cadmium above those indicative of EP toxicity. Few tests of bottom ash or combined fly and bottom ash indicate levels of metals above such levels. EPA is in the process of obtaining more reliable data on ash characteristics and leachability.

If the ash generated by a municipal waste combustion facility were to be managed as a hazardous waste, the cost of managing that ash would be expected to increase substantially.

The EPA's findings concerning ash disposal will be issued as they are completed. Unfortunately, they were not available for inclusion in this report. Therefore, the remainder of this report and the documents published with it focus on potential environmental effects of emissions from municipal waste combustors to the atmosphere.

## 3.2 EMISSIONS TO THE ATMOSPHERE*

Recently, concerns have been raised about emissions of pollutants to the atmosphere from municipal waste combustors. As discussed in the Introduction, much of this concern was over emissions of CDD and CDF, but other pollutants of concern have also been cited. As part of the integrated study of municipal waste combustion, EPA attempted to collect as much data on emissions from municipal waste combustors as was available. Summary matrixes showing emissions data collected by the EPA are shown in Tables C-1 and C-2 in Appendix C. The first summary table shows almost 50 facilities for which the EPA has documented test reports to support the test data. The second compilation is of data from emission tests about which the agency has little supporting information. These data include emission tests conducted in North America, Western Europe, and Japan.

Comparison of the data from different tests is difficult because the facilities vary widely in design and operating conditions, the tests were conducted with different objectives and different protocols, and the level of detail of the reported data varies. Further, the specific sampling and analysis methods were not the same for all tests. These differences make it difficult not only to make comparisons among combustors tested but also to draw conclusions about the entire population of combustors.

To make the most of existing emissions data, a compilation of test data has been assembled as a part of this effort to address environmental effects of municipal waste combustion. The compilation is presented in the document titled "Municipal Waste Combustion Study: Emissions Data Base for Municipal Waste Combustors."[16] Information concerning the units tested, operating conditions, and sampling and analytical protocols has also been included with the emissions measurement data.

The emissions data gathered to date from municipal waste combustors show a variety of pollutants emitted from their stacks at widely varying concentrations. A summary of the ranges measured for various pollutants exiting the plants is shown in Table 3-1. The data are shown for the three main classes of municipal waste combustion units: mass burn, modular, and RDF-fired. These data were collected from about 30 full-scale facilities for which documented test data and sampling and analytical methodologies were available. All emissions data have been normalized to 12 percent $CO_2$.

---

*The emissions data presented in this chapter are from Reference 16, Municipal Waste Combustion Study: Emissions Data Base for Municipal Waste Combustors. All data are shown on the basis of 12% $CO_2$.

The emissions numbers shown in Table 3-1 comprise emissions measured from municipal waste combustors that are equipped with widely varying control devices. The effects of different control devices on emissions of a given pollutant can be seen in widely varying stack emissions, contributing to the wide range shown in the table. The numbers shown do not distinguish among control devices in use. Existing municipal waste combustors are generally equipped with particulate matter control devices only, if they are equipped with control devices of any kind. Virtually all existing mass burn units (which tend to be larger) are equipped with some sort of particulate matter collection device. Thirty-six of 56 existing modular facilities now operating in the U. S. (which tend to be smaller and carry over fewer particulate emissions because of their design) are equipped with no add-on control devices.[6] However, all new, mass burn and RDF facilities and most new modular facilities are expected to be equipped with efficient particulate matter control devices. Only two existing facilities currently are equipped with scrubbers in addition to particulate matter control devices,[6] but many new facilities are expected to incorporate some type of gas scrubber for control of other pollutants.

These control devices are being incorporated in response to regulatory strategies at both the Federal and State levels. The control of particulate emissions from new municipal waste combustors is required by Federal standards. Some states, particularly those with the largest numbers of new units, are also requiring control of a variety of pollutants through the use of add-on control equipment and, in some cases, (e.g., California and in New York) furnace operating requirements.[6]

Remembering all the previous comments on the difficulty of comparing the emissions data, it may be useful to look more closely at the emissions test data for selected pollutants. Looking for trends or patterns, the facilities associated with the extremes of the ranges shown in Table 3-1 have been

## TABLE 3-1. SUMMARY OF EMISSIONS MEASURED FROM THE THREE MAJOR CLASSES OF MUNICIPAL WASTE COMBUSTORS[a]

| Pollutant | Mass Burn | Modular | RDF-Fired |
|---|---|---|---|
| Particulate matter | 5.5 - 1,530 mg/Nm$^3$<br>(0.002 - 0.669 gr/dscf) | 23 - 300 mg/Nm$^3$<br>(0.012 - 0.13 gr/dscf) | 220 - 530 mg/Nm$^3$<br>(0.096 - 0.230 gr/dscf) |
| Sulfur dioxide | 0.04 - 401 ppmdv | 61 - 124 ppmdv | 55 - 188 ppmdv |
| Nitrogen oxides | 39 - 380 ppmdv | 260-310 ppmdv | 263 ppmdv[b] |
| Carbon monoxide | 18.5 - 1,350 ppmdv | 3.2 - 67 ppmdv | 217 - 430 ppmdv |
| Hydrogen chloride | 7.5 - 477 ppmdv | 160 - 1270 ppmdv | 96 - 780 ppmdv |
| Hydrogen fluoride | 0.62 - 7.2 ppmdv | 1.1 - 16 ppmdv | 2.1 ug/Nm$^3$ [b] |
| Arsenic | 0.452 - 233 ug/Nm$^3$ | 6.1 - 119 ug/Nm$^3$ | 19 - 160 ug/Nm$^3$ |
| Beryllium | 0.0005 - 0.33 ug/Nm$^3$ | 0.096 - 0.11 ug/Nm$^3$ | 21 ug/Nm$^3$ [b] |
| Cadmium | 6.2 - 500 ug/Nm$^3$ | 21 - 942 ug/Nm$^3$ | 34 - 370 ug/Nm$^3$ |
| Chromium | 21 - 1,020 ug/Nm$^3$ | 3.6 - 390 ug/Nm$^3$ | 490 - 6,700 ug/Nm$^3$ |
| Lead | 25 - 15,000 ug/Nm$^3$ | 237 - 15,500 ug/Nm$^3$ | 970 - 9,600 ug/Nm$^3$ |
| Mercury | 9 - 2,200 ug/Nm$^3$ | 130 - 705 ug/Nm$^3$ | 170 - 440 ug/Nm$^3$ |
| Nickel | 230 - 480 ug/Nm$^3$ | <1.92 - 553 ug/Nm$^3$ | 130 - 3,600 ug/Nm$^3$ |
| TCDD | 0.20 - 1,200 ng/Nm$^3$ | 1.0 - 43.7 ng/Nm$^3$ | 3.5 - 260 ng/Nm$^3$ |
| TCDF | 0.32 - 4,600 ng/Nm$^3$ | 12.2 - 345 ng/Nm$^3$ | 32 - 680 ng/Nm$^3$ |
| PCDD | 1.1 - 11,000 ng/Nm$^3$ | 63 - 1540 ng/Nm$^3$ | 54 - 2,840 ng/Nm$^3$ |
| PCDF | 0.423 - 15,000 ng/Nm$^3$ | 97 - 1810 ng/Nm$^3$ | 135 - 9,100 ng/Nm$^3$ |

[a] See Appendix C for summary of facilities represented in emissions data for each pollutant category. Results summarized are from full scale commercial facilities only.

[b] Only one test.

identified and are discussed in the following sections. Supporting detail concerning unit types and test conditions may be found in the volume titled "Municipal Waste Combustion Study: Emission Data Base for Municipal Waste Combustors."[16]

It should be noted that the concentration ranges reported were measured during relatively short duration tests, usually compliance tests, performed under optimum conditions. In particular, the levels at the low end of the ranges may not be achievable at all combustors and may not be achievable on a continuous basis even by the specific combustors tested.

In addition, the levels at the low end of the ranges have not been found at the same facility for all pollutants. In some cases, achieving a low level of one pollutant is likely to make it more difficult to achieve a low level of others, e.g., achieving low levels of organic emissions through combustion optimization will make it more difficult to achieve low levels of nitrogen oxide emissions. Thus, the levels at the low end of the ranges are not all likely to be achievable at the same facility.

### 3.2.1 Particulate Matter

A benchmark against which the particulate matter concentrations measured in stack gases from municipal waste combustors can be compared is the NSPS of 0.08 gr/dscf (183 mg/Nm$^3$), established in 1971. Also, the newly promulgated NSPS for industrial boilers, which would apply to units of 100 million Btu/hour (270 tons per day of municipal waste) or larger that generate steam, limits particulate emissions to 0.1 lb/million Btu (43 ng/Joule) of heat input, which is equivalent to about 0.04 gr/dscf (92 mg/Nm$^3$), assuming the composition of waste shown in Appendix D.

As noted generally about all the emission test data, the range of particulate matter concentrations measured in combustor stack gases is large, especially for mass burn units, covering several orders of magnitude. Even though the range is large, the measured particulate concentrations tend to reflect the age of the technology in use and the type of control device in use.

The lowest concentrations were measured from two relatively new units, one equipped with a high efficiency (99.9%) electrostatic precipitator (ESP) and one equipped with a scrubber/fabric filter system. The lowest value for particulate concentrations from mass burn units (5.49 mg/Nm$^3$) was measured at Unit 1 of the Baltimore, Maryland, facility, a large, recently constructed facility. The Baltimore facility achieved an emission level of 6.2 mg/Nm$^3$ at Unit 2 during a test program conducted by the EPA later in the same year (1985). Another low particulate matter concentration (9.15 mg/Nm$^3$) was reported from a combustor in Wurzburg, Germany. This new facility is equipped with a dry scrubber/fabric filter. Other facilities equipped with ESPs or dry scrubber/fabric filter combinations have reported particulate matter concentrations in the range of 11 to 30 mg/Nm$^3$. (Marion County, Oregon; Tulsa, Oklahoma; Tsushima, Japan; Malmo, Sweden; and Munich, Germany.)

At the high end of the range of particulate matter concentrations, two refractory mass burn combustors reported high levels. The highest (1530 mg/Nm$^3$) was reported from the combustor at Mayport Naval Station in 1980. The particulate matter emission control device in use was a multiple-cyclone dust collector. This type of dust collector is not as effective as newer particulate emission control technologies. Another high value for particulate matter concentrations (1330 mg/Nm$^3$) was measured from Unit 2 of the Philadelphia Northwest facility, where particulate matter emission control is accomplished with an ESP.

This high concentration reported from one unit of the Philadelphia facility may be anomalous. The value of 1330 mg/Nm$^3$ is the average of three determinations of which one was extremely high. During the same series of tests, the average for Unit 1 of the same facility was 252 mg/Nm$^3$. The other two measurements for Unit 2 were nearer the levels measured for Unit 1. Of the waterwall mass burn combustors, the highest value (917 mg/Nm$^3$) was reported from Hampton in 1981. The Hampton facility is equipped with an ESP for control of particulate matter emissions. This combustion facility has been noted for several design and operational problems. Those problems are analyzed in more detail in the volume titled, "Municipal Waste Combustion Study: Combustion Control of Organic Emissions."[17]

Measured particulate matter stack gas concentrations for modular units are available from only six facilities. The data from these units show a much narrower range of values than those measured for mass burn units. The modular combustors for which stack gas particulate concentration data are available are of the starved air, Consumat design. Uncontrolled particulate matter concentrations in stack gases from these units are generally lower than uncontrolled concentrations from mass burn units because of lower air velocities, resulting in less carry-over of ash. Uncontrolled particulate concentrations measured at modular units range from 170 to 300 mg/Nm$^3$ compared with uncontrolled concentrations of 2,200 to 8,500 mg/Nm$^3$ measured at mass burn units. Ultimate stack concentrations from existing modular combustors may be higher, however, because they generally are not equipped with particulate matter emission control devices, while the mass burn units usually have them. Even so, because modular units are smaller, their total mass emissions of particulate matter generally are lower than the totals from mass burn facilities. Additionally, new modular combustors are generally expected to be equipped with particulate matter control devices.

The low value for modular units (23 mg/Nm$^3$) was measured at Barron County, Wisconsin, an ESP-controlled facility. Another facility, the Tuscaloosa facility, is also equipped with an ESP. Particulate matter concentrations measured at Tuscaloosa were 140 mg/Nm$^3$. However, this controlled particulate matter concentration is not considered representative of normal levels because of noted problems with the control equipment during the test. The high particulate matter concentration for modular units (300 mg/Nm$^3$) was measured at the 90 Mg/day combustor in Dyersburg in 1982. Testing was performed at a feed rate of 45 Mg/day, and the feed during the test was about 30 percent industrial and 70 percent municipal waste. The remaining particulate matter emissions data were gathered from testing under several different operating conditions at the Prince Edward Island combustion facility and range from 173 to 255 mg/Nm$^3$. The value obtained under normal conditions was 214 mg/Nm$^3$. Neither Dyersburg nor the Prince Edward Island facility have add-on air pollution control systems.

As with the modular units, the amount of data available for RDF-fired units is limited. The low particulate matter emission value for RDF units (220 mg/Nm$^3$) was measured at the Niagara facility. The facility fires shredded waste from which ferrous metals have been removed. Particulate matter emissions are controlled using ESPs. A particulate matter concentration of 89 mg/Nm$^3$ was measured at the Hamilton-Wentworth facility in Ontario, Canada, during normal load using only the lower overfire air port. This concentration was measured during one test run only. Emission test data taken under normal conditions showed 518 mg/Nm$^3$. The high particulate matter concentration for RDF-fired units (530 mg/Nm$^3$) was measured at the Akron facility in 1981. At Akron, processing of RDF includes shredding, air classification, and magnetic separation. Particulate matter emissions are controlled by an ESP.

The lowest uncontrolled particulate matter concentration from RDF-fired facilities was measured at Malmo, Sweden. A concentration of 4330 mg/Nm$^3$ particulate matter was measured upstream of very efficient control equipment. It should be noted that this unit is a relatively new unit designed as a mass burn unit and differs from typical RDF designs. When the unit was fired with unprocessed refuse, uncontrolled particulate matter concentrations were 4,450 mg/Nm$^3$, nearly the same as the RDF-fired concentration. Controlled levels measured while operating in the mass burn mode were 23.2 mg/Nm$^3$.

### 3.2.2 Sulfur Dioxide

The concentration of $SO_2$ measured in stack gases from municipal waste combustors depends directly on the amount of sulfur in the feed. Although it can be highly variable, a typical value for sulfur content of municipal waste is about 0.12 percent, and 30-60 percent of that is converted to $SO_2$. The balance remains with the bottom ash or is absorbed on fly ash. Sulfur is associated with such items as asphalt shingles, tires and other miscellaneous items in the waste feed.

For purposes of comparison, the sulfur content of coal being burned in the U. S. ranges from about 0.5 to about 5 percent. If high sulfur coal were burned in utility boilers without $SO_2$ controls, the resulting uncontrolled concentrations of $SO_2$ in stack gases could be as high as 3,000 ppm or higher. Another comparison point, the 1978 NSPS for $SO_2$ emissions from utility boilers, allows $SO_2$ emissions concentrations of 100 to 500 ppm $SO_2$, depending on the sulfur content of the coal. These controlled $SO_2$ levels generally are higher than uncontrolled concentrations in stack gases from municipal waste combustors, but as shown in the table, the high end of the range for mass burn units is comparable to the controlled level for coal-fired utility boilers.

Although the sulfur content in the waste is the ultimate determinant and major cause of variability in $SO_2$ concentrations measured, the emissions test data indicate that the control equipment in use is a major factor in the $SO_2$ concentrations measured in the combustor exhaust. As might be expected, combustors equipped with alkaline scrubbers tend to have lower levels of $SO_2$ in their stack gases. The low end of the range of sulfur dioxide stack gas concentrations for mass burn units was measured at a Japanese unit in Tsushima in 1983. The Tsushima facility is controlled with a Teller dry scrubber/fabric filter system. The $SO_2$ concentration upstream of the control system was 12.7 ppm; the concentration measured downstream of the control system was 0.040 ppm. The reduction across the control device represents a control efficiency of greater than 99.7 percent. The data reported for the composition of the waste feed at Tsushima showed that the average sulfur content of the waste is 0.38 percent on a wet basis. This is comparable to the sulfur content of municipal waste generated in North America; however, the uncontrolled $SO_2$ concentrations are about an order of magnitude lower than those at any other facility tested. Moreover, outlet $SO_2$ concentrations are more than two orders of magnitude less than any other reported values, including those from other facilities using dry scrubbing. These discrepencies make comparisons to $SO_2$ concentrations measured at other units questionable. The next lowest $SO_2$ concentrations were measured at a Quebec City pilot-scale test on a slip stream from a full-scale waterwall combustor. The temperature of the inlet gas to a scrubber/fabric filter system was varied during the test; the lowest concentration (4.86 ppm $SO_2$) was measured at the lowest temperature (110°C). The $SO_2$ concentration measured during the pilot-scale test increased with increasing temperature up to 90.3 ppm at 200°C. Another low $SO_2$ value, 13.5 ppm, was reported from a unit in Kure, Japan, equipped with two 75 Mg/day rotary combustors and an ESP followed by a wet scrubber. The next lowest $SO_2$ concentration, 41.5 ppm, was measured in 1986 at the Marion County unit in Brooks, Oregon. The Marion County facility is a new facility equipped with a dry scrubber/fabric filter system.

The high $SO_2$ emission measurement, 401 ppm, was obtained at the Philadelphia Northwest facility, equipped with an ESP and no additional control devices. This level and the other value for Philadelphia of 375 ppm are inexplicably higher than the $SO_2$ concentrations measured at the other mass burn units. $SO_2$ concentrations in exhaust gases from mass burn units equipped with ESPs or other particulate matter control devices are about the same as $SO_2$ concentrations measured in the inlets to the control devices for those combustors equipped with scrubbing systems. This is to be expected because ESPs do not remove $SO_2$, nor do cyclones. These uncontrolled $SO_2$ concentrations generally range between about 80 and 140 ppm, levels significantly lower than controlled levels required for fossil fuel-fired boilers.

Modular unit $SO_2$ concentration data compiled in the EPA's emission data base are taken from only two facilities, Prince Edward Island (under a variety of conditions) and Red Wing (under normal conditions). The low value of 61 ppm was obtained under "normal" conditions at Prince Edward Island. The highest value obtained at Prince Edward Island of 87 ppm was measured under low secondary chamber temperature conditions. The highest level of 124 ppm was achieved at the Red Wing facility under normal conditions. The concentrations are roughly comparable to the uncontrolled concentrations measured for mass burn units. A concentration of <29.3 ppm was reported at North Little Rock, Arkansas; however, data were not available to correct the reported value to a dry basis, so it cannot be compared.

Sulfur dioxide emissions data for RDF-fired combustors are available for only three facilities. The low value of 55 ppm was measured in 1984 at the Hamilton-Wentworth, Ontario facility which was equipped with an ESP for control of particulate matter emissions. The high value of 188 ppm, was measured at the Albany, New York facility in 1984. Although it is difficult to make any meaningful comparisons with this small amount of data, the $SO_2$ concentrations are again consistent with uncontrolled $SO_2$ concentrations measured at mass burn units.

### 3.2.3 Hydrochloric Acid

The concentration of HCl in stack gases from municipal waste combustors is related to the chlorine content of the feed. Major chlorine sources in municipal waste are plastics and paper, materials that also provide the largest heating value in the waste. By way of comparison to the ranges shown in Table 3-1, typical uncontrolled HCl concentrations in stack gases from coal-burning utility boilers could range from about 60 ppm for average chlorine content coal to 120 ppm for high chlorine content coal. These HCl concentrations considered with the previous discussion of $SO_2$ concentrations indicate that the acid gas of primary concern with municipal waste combustors is usually HCl, while with fossil fuel-fired boilers the primary acid specie is usually $SO_2$.

The major determinant of the ultimate concentration of HCl in stack gases exiting a municipal waste combustor, other than feed composition, is the control device in use. It is logical to expect facilities equipped with scrubbers have significantly lower HCl concentrations because HCl is easily removed with scrubbing. This expectation is borne out by the EPA's emission test data.

For mass burn combustors the lowest stack gas concentration for hydrochloric acid was measured at the Quebec City scrubber/fabric filter pilot scale testing in 1985-1986. The lowest HCl concentration (3.99 ppm) was measured at the lowest temperature (110°C) test condition. Measured HCl concentrations leaving the fabric filter increased with increasing temperature to 104 ppm at 200°C. The next lowest HCl concentration (7.5 ppm) was measured at the Tsushima facility. The lowest concentration achieved at a commercial-scale North American facility (12 ppm) was measured during the recent test of the Marion County facility equipped with a dry scrubber/fabric filter system. The high end of the range for mass burn units (477 ppm) was measured upstream of air pollution control equipment at the Gallatin, Tennessee facility in 1983. Emission control equipment consisted of a cyclone and an electrostatically assisted fabric filter, neither of which is designed to reduce HCl stack gas concentrations. Another high HCl concentration was measured at a new mass burn combustor in Tulsa. Stack gas concentrations of 402 and 421 ppm were measured downstream of an electrostatic precipitator. This facility is notable because CDD/CDF concentrations measured there were very low, a condition attributable to optimized combustion.

Hydrochloric acid emissions test data are available for only four modular facilities; all are Consumat, starved air units, and two of these modular facilities are equipped with post combustion controls. The low value of 160 ppm was measured at the Dyersburg facility during testing in 1982. The high value (1270 ppm) was measured at the Red Wing facility. The second highest value (768) was obtained under high temperature secondary chamber conditions at Prince Edward Island. Under "normal" conditions at Prince Edward Island 716 ppm HCl was measured in the stack gas. The Barron County facility reported an intermediate concentration of 460 ppm. The Red Wing HCl concentration is noticeably higher.

None of the available HCl emissions data for RDF-fired combustors were obtained from measurements downstream of acid gas control devices; therefore, they essentially represent uncontrolled HCl stack gas concentrations. The lowest level of HCl concentration (96 ppm) from an RDF unit was measured at Wright Patterson Air Force Base in 1982. The combustor there is an 11,000 MJ/hr boiler designed to burn coal. During the test the boiler was fired with densified RDF. Particulate matter emission control equipment at the Wright Patterson facility consists of a multicyclone followed by an ESP. The high value of 780 ppm was reported in 1983 from a combustor in Malmo, Sweden. The Malmo facility was designed as a mass burn unit. These emissions were measured during a test in which RDF was fired in the combustor designed to fire unprocessed waste. Although this plant is equipped with a cyclone/dry scrubber/ESP/fabric filter combination which should control HCl emissions, the measurement reported was upstream of the control device, representing an uncontrolled HCl stack gas concentration. Other HCl concentrations measured from RDF-fired plants range from 350 ppm measured at the Albany facility to 450 ppm measured at the Akron facility in 1981. These values are typical of the expected range of uncontrolled HCl stack gas concentrations.

### 3.2.4 Metals

Metals and metallic compounds are found distributed throughout municipal refuse, not just associated with large metallic objects. Many metals, such as silver, chromium, lead, tin, and zinc, are used in metallic surface coatings, galvanizing, and solders. These metals may volatilize during the combustion process. Plastic objects contain metallic compounds (cadmium, in particular) as stabilizers and other additives. Metals, such as cadmium, chromium, and lead, are also found in inks and paints associated with paper, fabric, and plastic substrates. Discarded batteries are sources of mercury, nickel, and cadmium. Metals and metallic compounds may change phases or may form new metallic compounds, but they are not destroyed in the combustion process. The metals and metallic compounds will leave the combustor in the stack gas or in the ash residues. Operating temperature affects metals emissions by affecting the partitioning between phases. Thus one would expect stack gas concentrations of metals to be related to feed concentration and operating conditions. But the data also tend to show a strong effect of control devices.

Table 3-2 shows the facilities associated with the extremes of the concentration ranges for a few selected metals measured in stack gases from mass burn combustors. As the table shows, the Quebec City facility is associated with the low end of the range for the four metals shown. As mentioned before, the Quebec City data were generated just recently on a slip stream from a full-scale combustor. A dry scrubber/fabric filter system was tested at several fabric filter operating temperatures, thus, the ranges shown for Quebec. The Malmo, Wurzburg, and Munich facilities are all equipped with dry scrubbers. The Kure facility, however, is equipped with an ESP/wet scrubber combination. While the scrubber-equipped combustors show lower metals concentrations in the stack gases, the data also indicate that ESPs may be operated as effective control devices for some metals. For example, arsenic concentrations measured downstream of the ESP at Baltimore were 6.29 ug/Nm$^3$; this represents 97 percent reduction in the uncontrolled level of 240 ug/Nm$^3$. The Baltimore facility's ESP also achieved 99 percent reduction of chromium. The controlled concentration levels measured at Baltimore are higher than those measured at facilities equipped with scrubbers, but they are lower than those measured at other ESP-equipped facilities.

The high end of the range of stack gas concentrations at mass burn units for these selected metals is associated with the Hampton and Braintree facilities. The Hampton facility, as previously noted, has been notable for several design and operational problems. Those problems are discussed in more detail in the report titled "Municipal Waste Combustion Study: Combustion Control of Organic Emissions."[17] Like Hampton, the Braintree system was equipped with an ESP for particulate removal.

## TABLE 3-2. MASS BURN FACILITIES FOR WHICH HIGHEST AND LOWEST EMISSION LEVELS WERE MEASURED FOR SELECTED METALS

| Metal | Facility(s) Showing Low Concentration | Emission Concentration ($ug/Nm^3$) | Sampling and Analytical Methods | Facility(s) Showing High Concentration | Emission Concentration ( $ug/Nm^3$) | Sampling and Analytical Methods |
|---|---|---|---|---|---|---|
| As | Munich[a] | 0.45 | o | Hampton[a] | 233 | i |
| | Wurzburg[b] | 0.007 | d | | | |
| | Quebec[a] | 0.022 - 0.073 | e | | | |
| Cd | Quebec[a] | <detection limit - 0.64 | f | Hampton[a] | 500 | j |
| | Malmo[c] | 6.2 | g | Braintree[a] | 475 | k |
| | Wurzburg[b] | 6.9 | d | | | |
| | Munich[a] | 8.6 | o | | | |
| Pb | Quebec[a] | 1.23 - 6.5 | f | Braintree[a] | 15,000 | k |
| | Wurzburg[b] | 13.7 | d | Hampton[a] | 9,500 | l |
| | Marion County | 25.1 | | | | |
| Hg | Quebec[a] | 10 - 43 | h | Hampton[a] | 2,200 | m |
| | Kure[n] | 8.69 | n | | | |

[a] Both particulate and condensibles analyzed.

[b] Particulate only analyzed. One test run only.

[c] Not clear, possibly only condensibles analyzed.

[d] Flow sensor, multiclone sampling, analysis by atomic absorption.

[e] EPA Method 5, flameless atomic absorption.

[f] EPA Method 5, direct current plasma emission spectrometry.

[g] $HNO_3$ impingers, atomic absorption.

[h] $KMnO_4$ impinger, flameless atomic absorption.

[i] SASS train. Volatile metals trapped in $H_2O_2$ and ammonium persulfate/$AgNO_3$ impingers. Volatile phase analysis by hydride generation. Filter catch analysis by X-ray fluorescence.

[j] SASS cyclone/filter catch analyzed by X-ray fluorescence.

[k] EPA Method 5/SASS. Analyzed by atomic absorption and spark source mass spectrometry.

[l] SASS train. Volatile metals trapped in $H_2O_2$ and ammonium persulfate/$AgNO_3$ impingers. Analysis using graphite furnace and X-ray fluorescence.

[m] SASS train. Volatile metals trapped in $H_2O_2$ and ammonium persulfate/$AgNO_3$ impingers. Analysis by flameless UV technique (EPA method 245.1).

[n] unidentified method.

[o] Flow sensor, multiclone sampling system. Analysis by atomic absorption

Conclusions drawn from these data must be drawn with caution. A serious complicating factor involved in the metals emissions data may prevent definite conclusions from being drawn. Sampling and analytical methods used during the testing reported here were not constant. In some emissions tests only metals in the form of particulate matter were measured. In other tests both particulate matter and the condensibles were analyzed for metals. Moreover, sampling and analytical techniques used for measuring metals in either or both phases differed among the emissions tests, as shown in the table. The complications these differences introduce are clear. While it is unlikely that the differences in the metals concentrations reported are due totally to different sampling and analytical protocols, the contributions to the differences are unknown. The EPA is investigating the issue of data comparability.

The data for mercury concentrations in combustor stack gases, with the exception of the Quebec City data, do not show outstanding control with the use of either ESPs or scrubber/fabric filter systems. Mercury concentrations measured at inlet and outlet to scrubber/fabric filter systems at Malmo and Tsushima show only 30 to 40 percent reduction, while ESP data showed no control. Metallic mercury is generally thought to volatilize, so control might be accomplished through cooling and condensation. Research in Germany has also indicated a possible chemical reaction with alkaline sorbents.[18] Moreover, the data gathered at Quebec under varying temperature conditions indicate that it may be possible to optimize mercury control through cooling. This is a subject of continuing study. With respect to mercury, it should also be noted that the high end of the range of stack gas concentrations for mass burn facilities is an order of magnitude higher than such concentrations measured at other facilities.

Metals emissions data are available for only five modular units, Prince Edward Island, Dyersburg, Barron County, Tuscaloosa and Red Wing; all are Consumat systems. Three (Barron County, Tuscaloosa and Red Wing) are equipped with particulate matter control devices. Those facilities reporting the highest and lowest concentrations for the four metals being discussed here are shown in Table 3-3. The table shows that the stack test data from Dyersburg showed the lowest of the mercury concentrations. This concentration is lower

## TABLE 3-3. MODULAR FACILITIES FOR WHICH HIGHEST AND LOWEST EMISSION LEVELS WERE MEASURED FOR SELECTED METALS

| | Facilities Showing Low Concentrations | Emission Concentration | Sampling and Analytical Method | Facilities Showing High Concentrations | Sampling and Analytical Method | Emission Concentration |
|---|---|---|---|---|---|---|
| As | Prince Edward Island[a] | 6.09 ug/Nm$^3$ | d | Dyersburg[a] | c | 116 ug/Nm$^3$ |
| Cd | Barron County[b] | 21 ug/Nm$^3$ | - | Prince Edward Island[a] | d | 942 ug/Nm$^3$ |
| Pb | Barron County[b] | 240 ug/Nm$^3$ | - | Prince Edward Island[a] | d | 15,500 ug/Nm$^3$ |
| Hg | Dyersburg[a] | 130 ug/Nm$^3$ | e | Prince Edward Island[a] | d | 705 ug/Nm$^3$ |

[a] Both phases analyzed.

[b] Unknown which phases were analyzed.

[c] Arsenic concentrations were measured by EPA Method 108. The filter and solids contained in the 0.1 N NaOH rinse of the front half of the sampling train were analyzed by atomic absorption. The impingers and 0.1 N NaOH rinse were analyzed by atomic absorption.

[d] Sample train similar to that of Method 5. First two impingers contain 5 percent aqua regia, third impinger contained 2% $KMnO_4$ in 10% $H_2SO_4$. Analysis generally by direct current plasma emission spectrometry.

[e] Volatile trace elements trapped in liquid impinger train which contains $H_2O_2$ in the first impinger and ammonium persulfate in the following two impingers. Analysis using flameless, UV technique, EPA M245.1 (manual cold vapor technique).

than concentrations measured at some of the mass burn units equipped with alkaline scrubbers. Barron County reported the lowest measured concentrations for lead and cadmium. Prince Edward Island's stack test data were lowest for arsenic; the highest arsenic concentration was reported from Dyersburg. The highest cadmium and lead concentrations were measured at Prince Edward Island. The high cadmium concentration was measured under "normal" conditions. The high lead concentration was measured during a test run of a long feed cycle, but a similarly high concentration (14,400 ug/Nm$^3$) was measured under "normal" conditions. The highest mercury concentration (705 ug/Nm$^3$) was also measured at Prince Edward Island under "normal" conditions.

Metals data for two plants designed to fire RDF were available for comparison. The Albany and Akron facilities were both equipped with ESPs for particulate matter control. The metals analyses for Akron and Albany included both particulate matter and condensibles. Test data from the Albany facility showed stack gas concentrations an order of magnitude lower for arsenic, cadmium, and lead, than levels measured at the Akron facility. The mercury concentrations measured at Akron were somewhat lower, however. With only two units, it is hard to draw any firm conclusions. However, there is no indication that these units exhibit significant differences from the mass burn units in metals stack gas concentrations. The Malmo plant, a new mass burn unit fired with RDF, reported mercury and lead concentrations upstream of the control device similar to the concentrations reported for the Akron facility. But the cadmium emissions measured at Malmo were higher (488 ug/Nm$^3$) than those measured at Akron.

### 3.2.5 CDD and CDF

As pointed out in the beginning of Section 3.2, the test data available for CDD and CDF were not gathered with a statistically designed sampling plan for the industry, and the data assembled in this study are averages of test data from diverse facilities. Nevertheless, for purposes of this report these data are the best available to characterize potential emissions of CDD and CDF from municipal waste combustors.

The variability associated with measured CDD and CDF stack gas concentrations is the most noticeable observation about the emissions data.

These data have been summarized in Table 3-4 and graphically in Figures 3-1 and 3-2. As shown, the stack gas concentrations of CDD cover several orders of magnitude, showing the largest range for mass burn facilities for which there are the most data points. Another indication from the test data assembled by EPA is that alkaline scrubbing systems combined with fabric filters are effective at reducing CDD/CDF concentrations in stack gas. As shown in Table 3-4 and in Figures 3-1 and 3-2 and in the data summarized in the volume titled "Municipal Waste Combustion Study: Emission Data Base for Municipal Waste Combustors,"[16] those facilities equipped with alkaline scrubbers tend toward the lower end of the range of CDD concentrations. However, the data shown for facilities without alkaline scrubbers include some older units, while the units with alkaline scrubbers are all fairly new.

Table 3-5 shows which mass burn facilities are associated with the end points of the ranges shown for stack gas concentrations of selected CDD and CDF. As the table shows, the ranges cover five orders of magnitude. Marion County data were the lowest for four of the six classes shown in the table. Those measured at Quebec City and Wurzburg were the lowest for the other two. The Marion County combustion facility is a new facility, also equipped with a dry scrubber/fabric filter system. The Wurzburg facility is also equipped with an alkaline scrubber/fabric filter system. Both the Marion County and Wurzburg facilities are of Martin design. It should be noted that the Quebec City test data are pilot plant data, and it is not clear how the test results can be extrapolated to the population of full-scale combustors.

These low values show that alkaline scrubber/fabric filter control systems can effect good control of organic compounds like CDD and CDF. Low levels have also been achieved without a scrubber. Recently obtained data from Tulsa show that low concentrations might also be expected from municipal waste combustors with good combustion. The Tulsa facility is a new mass burn waterwall combustion facility. Particulate matter emissions are controlled by ESPs, but no additional control equipment is in use. It is currently unclear what contribution ESPs may make with respect to control of organic emissions, but most ESPs are run at temperatures high enough that little organic control

## TABLE 3-4. SUMMARY OF CDD/CDF EMISSIONS FROM MUNICIPAL WASTE COMBUSTORS

| | | Emissions, ng/Nm$^3$ at 12 percent $CO_2$[b] | |
|---|---|---|---|
| Facility | Test Condition[a] | CDD/CDF | TCDD |
| Chicago NW[c] | Normal | 258 | 8.39 |
| Hampton (1981) | Normal | 16,800 | 800 |
| Hampton (1983) | Normal | 9,630 | 214 |
| Hampton (1984) | Normal | 25,500 | 1,160 |
| Tulsa | Normal | 34.4 | 1.61 |
| North Andover | Normal | 348 | 8.38 |
| Saugus | Normal | 580 | 31.9 |
| Umea (Fall) | Normal | 501 | 51.6 |
| | Low temperature | 745 | 64.8 |
| Umea (Spring) | Normal | 492 | <12 |
| Marion County (DS) | Normal | 1.55 | 0.195 |
| Quebec (DI) | 110 | 2.65 | BD |
| | 125 | BD | BD |
| | 140 | 1.03 | BD |
| | 200 | 7.61 | BD |
| Quebec (SD) | 140 | BD | BD |
| | 140 & R | 1.33 | 0.0639 |
| Wurzburg (DS) | Normal | 49.9 | 1.91 |
| Philadelphia (NW1) | Normal | 11,300 | 378 |
| Philadelphia (NW2) | Normal | 5,620 | 365 |
| Cattaraugus[d] | Normal | 258 | 8.1 |
| Red Wing | Normal | 3,310 | 43.7 |
| Prince Edward Island | Normal | 395 | 3.05 |
| | Long | 428 | 5.09 |
| | High | 195 | 1.02 |
| | Low | 413 | 3.05 |
| Albany | Normal | 578 | 19.9 |
| Hamilton Wentworth | F/None | 9,230 | 590 |
| | F/Low back | 10,900 | 560 |
| | F/Back | 12,000 | 570 |
| | F/Back, low front | 20,900 | 3,500 |
| | H/None | 14,100 | 1,200 |
| | H/Low back | 11,500 | 700 |
| Wright Patterson | Normal | 228 | 3.47 |

---

[a] Test conditions defined in Reference 9, Municipal Waste Combustion Study Emission Data Base for Municipal Waste Combustors.

[b] BD = Below detection limit.

[c] No Penta CDD or Penta CDF measured. Values for CDD/CDF biased low.

[d] Values not corrected to 12 percent $CO_2$.

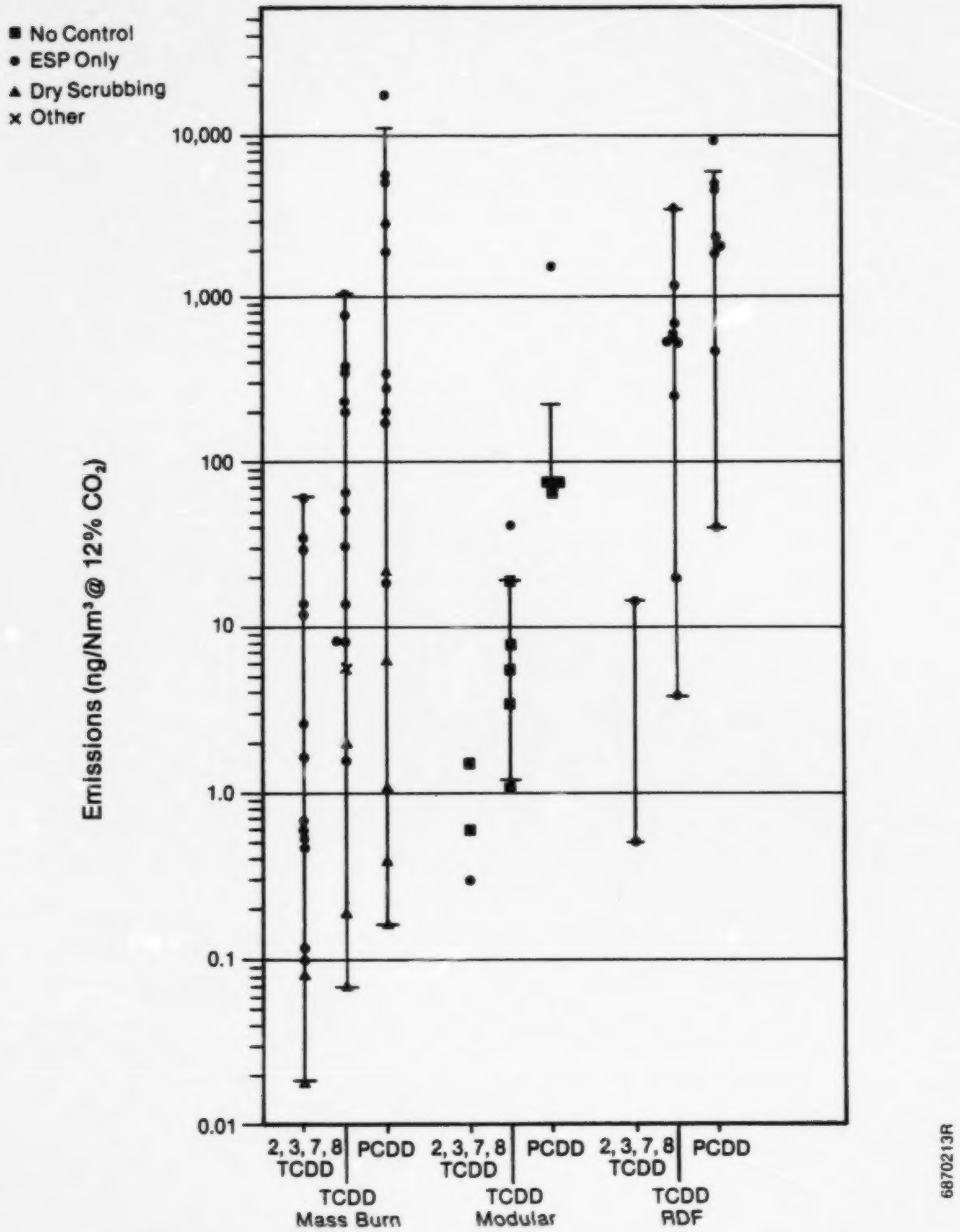


Figure 3-1. Summary of CDD Stack Gas Emissions Test Data.

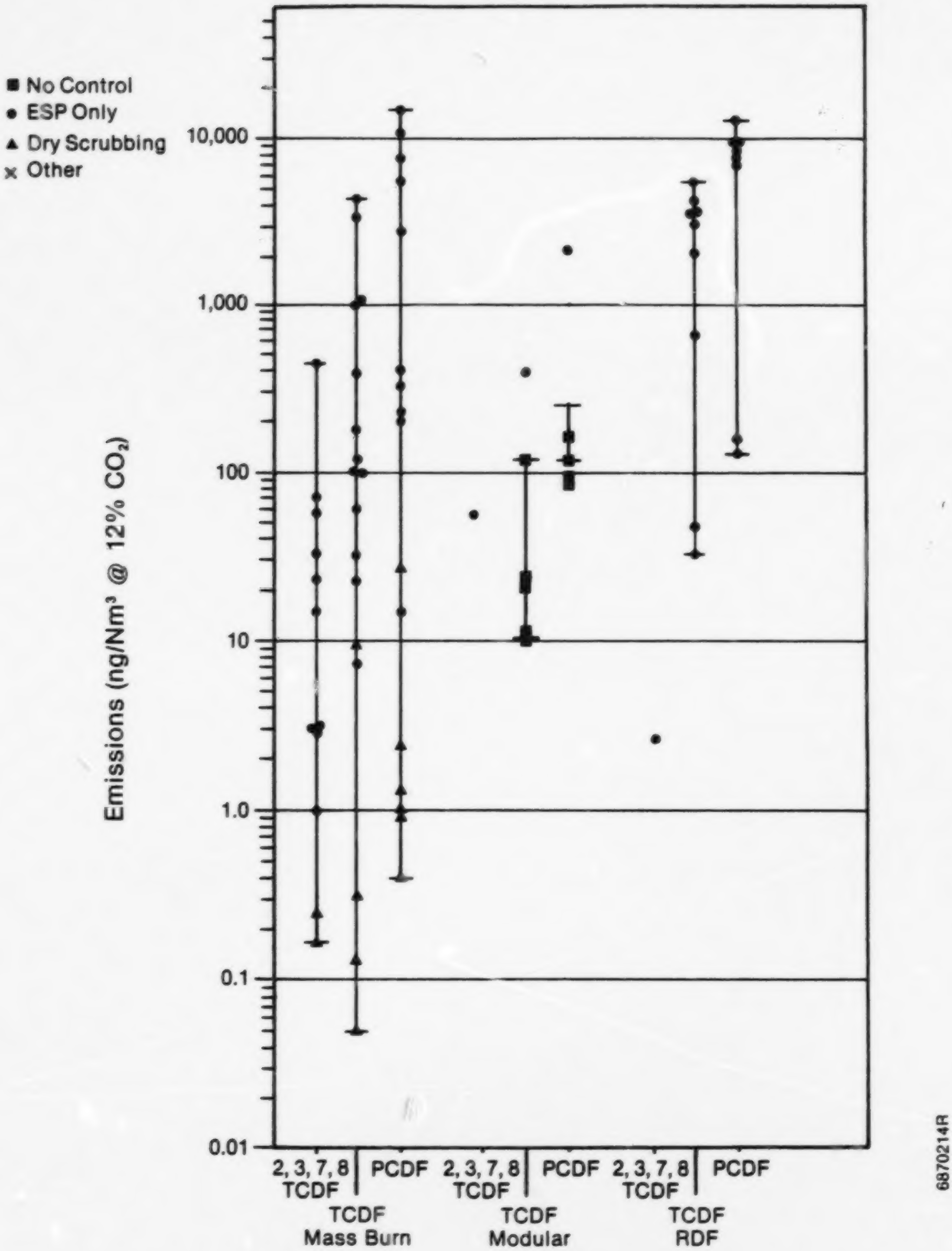


Figure 3-2. Summary of CDF Stack Gas Emissions Test Data.

TABLE 3-5. MASS BURN FACILITIES FOR WHICH HIGHEST AND LOWEST STACK GAS CONCENTRATIONS WERE MEASURED FOR SELECTED GROUPS OF CDD AND CDF

| Pollutant | Number of Facilities[b] | Facility(s) Showing Low Concentration | Concentration ($ng/Nm^3$) | Facility(s) Showing High Concentration | Concentration ($ng/Nm^3$) |
|---|---|---|---|---|---|
| 2,3,7,8-TCDD | 8 | Wurzburg | 0.018 | Hampton (1982) | 63 |
| TCDD | 9 | Marion County | 0.20 | Hampton (1984) | 1,200 |
| 2,3,7,8-TCDF | 7 | Marion County | 0.17 | Hampton (1984) | 450 |
| TCDF | 9 | Marion County<br>Quebec City (140° and Recycle)[a] | 0.32<br>0.13 | Hampton (1981) | 4,600 |
| CDD | 10 | Quebec City (110°)[a]<br>Marion County | 0.165<br>1.13 | Hampton (1984) | 11,000 |
| CDF | 10 | Marion County<br>Quebec City (140° and Recycle)[a] | 0.423<br>0.947 | Hampton (1984) | 15,000 |

[a] These data are from a pilot scale test of a dry scrubber/fabric filter system. The control equipment in use under ordinary circumstances is an ESP.

[b] Number of facilities for which documented test data available.

would be expected. Concentrations of CDD and CDF were measured at Tulsa as follows:

| | |
|---|---|
| TCDD | 1.61 ng/Nm$^3$ |
| PCDD | 18.9 ng/Nm$^3$ |
| TCDF | 7.31 ng/Nm$^3$ |
| PCDF | 15.5 ng/Nm$^3$ |

These values are the lowest CDD/CDF values in the emissions data base for mass burn facilities not using alkaline scrubbers. Moreover, because the ESP is not thought to contribute a significant amount of organic control, the concentrations measured are thought to result from relying on optimized combustion only. Note that these concentrations are similar to those measured at Wurzburg, a facility equipped with a dry scrubber/fabric filter system.

The combustion facility at Hampton was associated with each of the upper bounds of these classes of dioxins and furans. As mentioned previously, that unit is equipped with an ESP and has known design and operational problems. More information about the Hampton facility may be found in the volume titled "Municipal Waste Combustion Study: Combustion Control of Organic Emissions."[17]

There are only a few modular units for which the stack gas concentrations of CDD and CDF can be compared. In general, the concentrations measured at the modular units fall in the mid-range. They are higher than those measured at facilities equipped with alkaline scrubbers, but lower than the high values measured at mass burn units. The modular facilities represented in the data base are equipped with Consumat combustors. Two of them are equipped with ESPs. The high and low values for some of the classes of CDD and CDF are shown in Table 3-6. As the table shows, Prince Edward Island dominates the low end of the ranges, the Red Wing facility dominates the high end. The low values reported for Prince Edward Island were measured under high secondary chamber temperature conditions.

The range for RDF-fired facilities is very large, even though there are only 3 or 4 facilities available for analysis. This makes looking for trends or drawing conclusions particularly difficult. The low end of the range of TCDD concentrations shown was measured at Wright Patterson Air Force Base. The high concentration was measured at Akron. The concentrations measured for

### TABLE 3-6. MODULAR FACILITIES FOR WHICH HIGHEST AND LOWEST STACK GAS CONCENTRATIONS WERE MEASURED FOR SELECTED GROUPS OF CDD AND CDF

| Pollutant | Facility Showing Low Concentration | Concentration ($ng/Nm^3$) | Facility Showing High Concentration | Concentration ($ng/Nm^3$) |
|---|---|---|---|---|
| TCDD | Prince Edward Island | 1.0[a] | Red Wing | 44 |
| TCDF | Prince Edward Island | 12[a] | Red Wing | 350 |
| CDD | Prince Edward Island | 63[a] | Red Wing | 1500 |
| CDF | Prince Edward Island | 97[a] | Red Wing | 1800 |

[a] Measured under high secondary chamber temperatures.

TCDF again were lower at the Wright Patterson facility (32 ng/Nm$^3$) and higher at the Akron facility (680 ng/Nm$^3$). For PCDD, stack gas concentration data were available for a few additional units. As before, the low end of the range (54 ng/Nm$^3$) was measured at Wright Patterson, but for this class of compounds, the high value (2,840 ng/Nm$^3$) was measured at the Hamilton-Wentworth facility under normal load with both back overfire air ports in operation. Consistent with the other classes of CDD and CDF, the low value in the emission data base for PCDF concentration was measured at the Wright Patterson facility. The high value of 9,100 ng/Nm$^3$ was again measured at Hamilton-Wentworth under normal load with both back overfire air ports in operation. All of the RDF-fired facilities tested are equipped with ESPs.

# 4. OPTIONS FOR CONTROLLING EMISSIONS TO THE ATMOSPHERE

The pollutants shown in the summary emissions table (Table 3-1) include several major classes of substances for which control may be possible: particulate matter, organics, acid gases, metals, and $NO_x$. There are basically two approaches to controlling emissions from municipal waste combustors. One approach is to alter the combustion process to reduce emissions, sometimes called combustion control. The other is adding pollution control equipment to clean the combustion gases. This approach may be called post-combustion control, flue gas cleaning, or flue gas treatment. These two approaches are not exclusive, and are often used together for a comprehensive control strategy.

For municipal waste combustors the control problem involves a slate of pollutants. Moreover, application of control technology for one pollutant or class of pollutants may have positive or negative effects on control of other pollutants. For example, enhanced combustion should reduce the emissions of other organic pollutants in addition to CDD and CDF. Moreover, alkaline scrubbers, when combined with particulate control devices, can reduce not only acid gases but also some organic species and volatile metals. On the other hand, maximizing the combustion efficiency may increase the potential to form $NO_x$. Devising a control strategy, then, involves consideration of control techniques for each of the classes of pollutants present, but also requires consideration of the effects of a selected control technique on the whole list of pollutants.

In addition to considering positive and negative effects of air pollution control equipment on different air pollutants, another important consideration concerns cross-media effects. Some pollutants, notably metals, may be captured and prevented from being emitted to the atmosphere, but they are not destroyed. Increased capture means that the ash residues contain more metals.

The following sections describe available control techniques for each pollutant class. Then optimum strategies for controlling the whole list of pollutants from the stack gases of municipal waste combustors are considered. More complete discussions of combustion optimization and flue gas treatment may be found in two volumes: "Municipal Waste Combustion Study: Combustion Control of Organic Emissions"[17] and "Municipal Waste Combustion Study: Flue Gas Cleaning Technology."[19]

## 4.1 ORGANICS

The municipal waste combustion process essentially is designed to convert organic materials to $CO_2$ and water. Nonetheless, some organic materials are emitted. The presence of organics in the exhaust gas is a sign of incomplete combustion. Incomplete combustion can also be indicated by high levels of CO, so one would expect high levels of CO to be accompanied by high levels of organics.

This expectation is validated by a simple look at CDD/CDF concentrations, particular group of organic compounds, versus CO concentrations measured in stack gases from municipal waste combustors. Figure 4-1 shows average CDD/CDF and CO data gathered in the course of this study. Keeping in mind that these data represent averages of tests made using different methods from different types of combustors, using different types of control equipment, and noting that the variability is large, regression analysis is not advisable. Moreover, the data used are not adequate to establish a functional relationship between variables. Nevertheless, the trend toward higher CDD/CDF emissions with higher CO emissions is clearly evident. Further validation of trends between CDD/CDF and CO concentrations is seen in Table 4-1 which summarizes Spearman Rank Order Correlation results, a statistical test for monotonic relationships. This analysis is not a rigorous analysis for statistical correlation and, therefore, caution should be used in drawing conclusions. However, the graph and the Spearman Rank Order Analyses indicate that, in general, high CDD/CDF are associated with high CO concentrations and low CDD/CDF concentrations are associated with low CO concentrations.

Several theories have been postulated concerning ways that organic compounds, including CDD and CDF, may appear in stack gases from municipal waste combustors. The best supported theories for the formation of CDD/CDF are summarized in Figure 4-2.[17]

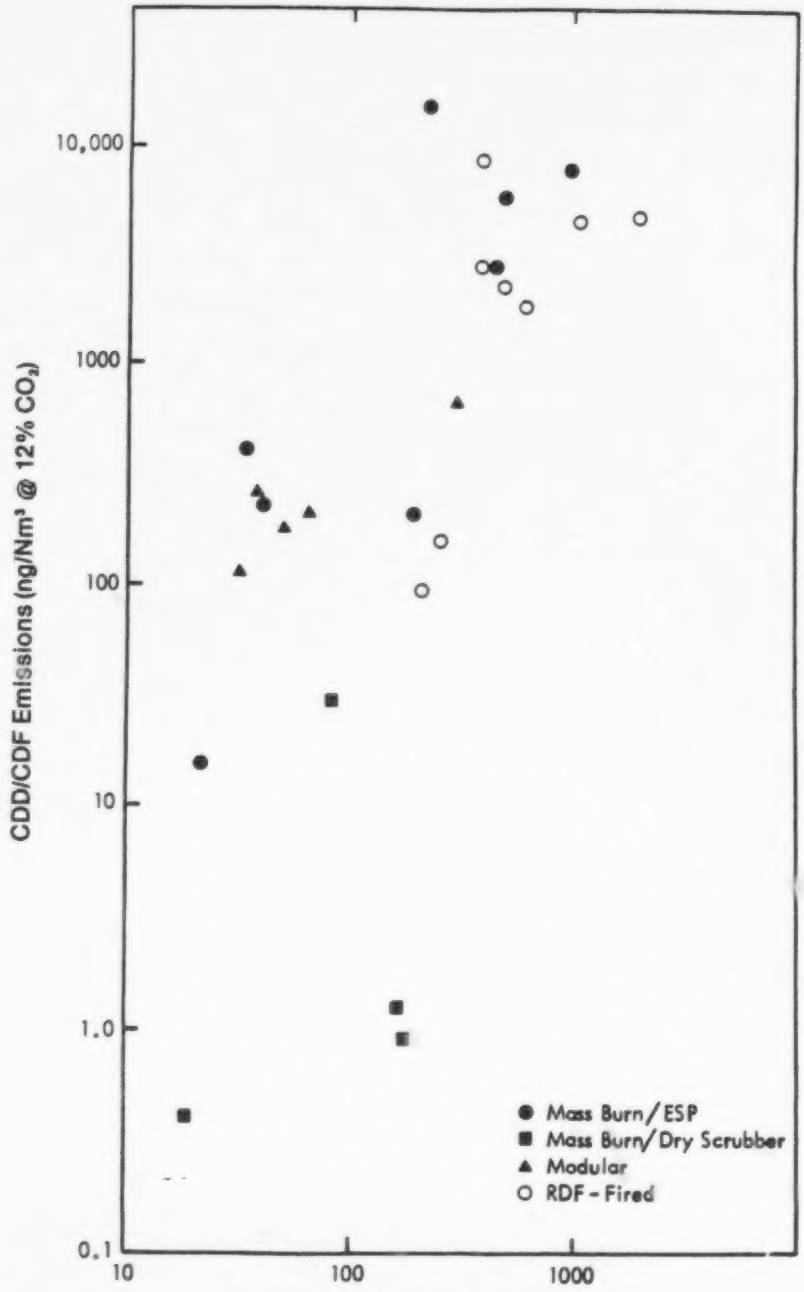


Figure 4 - 1. Comparison of CDD/CDF Stack Gas Concentrations to CO Stack Gas Concentrations

TABLE 4-1. RANK ORDER CORRELATION RESULTS FOR CO vs. CDD/CDF

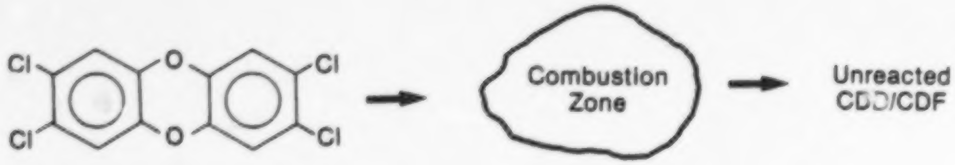
| Combustor Type | No. of Tests | $r_s$ |
|---|---|---|
| Mass burn | 14 | 0.52[a] |
| Modular | 6 | -0.40 |
| RDF-fired | 7 | 0.07 |
| Total | 25 | 0.69[b] |

$r_s$ = Spearman's rank order correlation coefficient.

[a] A positive relationship is indicated at the 0.05 level of significance.

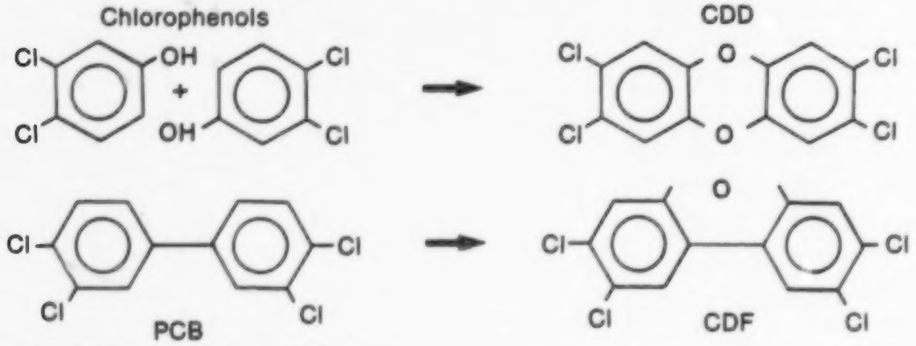
[b] A positive relationship is indicated at the 0.001 level of significance.

## I. CDD in Refuse


Cl
O
Cl
Cl
O
Cl
Combustion Zone
Unreacted CDD/CDF

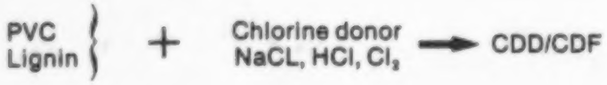
Evidence: Occasional CDD/CDF contamination in refuse

## II. Formation from Related Chlorinated Precursors


Chlorophenols
Cl
OH
+
OH
Cl
Cl
Cl
CDD
Cl
O
O
Cl
Cl
Cl
Cl
Cl
Cl
Cl
PCB
O
Cl
Cl
Cl
Cl
CDF

Evidence: CDD/CDF on soot from PCB fires
Lab and bench studies of PCB, Chlorinated Benzene and Chlorinated Phenols yielded CDD/CDF

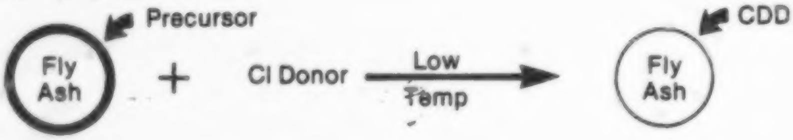
## III. Formation from Organics and Chlorine Donor



$$\left.\begin{matrix}\text{PVC}\\ \text{Lignin}\end{matrix}\right\} + \begin{matrix}\text{Chlorine donor}\\ \text{NaCL, HCl, Cl}_2\end{matrix} \longrightarrow \text{CDD/CDF}$$

Evidence: Lab scale tests of vegetable matter, wood, lignin, coal with chlorine source yielded CDD/CDF

## IV. Solid Phase Fly Ash Reaction


Precursor
Fly Ash
+
Cl Donor
Low
Temp
CDD
Fly Ash

Evidence: Lab scale demonstrating potential for ash catalysis reactions of CDD's to other homologues

687005R

Figure 4 - 2. Summary of Theories for CDD/CDF Municipal Waste Combustor Stack Gas

The first possible mechanism shown in Figure 4-2 involves breakthrough of unreacted organic species present in the refuse. A second theory involves the reaction of organic precursors in the waste. For example, relatively simple reactions can convert chlorophenols and polychlorinated biphenyls to CDD/CDF. These precursors can be in the refuse and can be produced by pyrolysis in oxygen-starved zones.

A third mechanism involves the synthesis of CDD/CDF from a variety of organics and a chlorine donor. Again, the simplest mechanisms involve those species that are structurally related to CDD/CDF; however, a full spectrum of plausible combustion intermediate chemistry could be proposed to lead to precursors and eventually to CDD/CDF.

The final possible mechanism shown involves catalyzed reactions of organic precursors escaping the combustion zone on fly ash particles at low temperatures. These hypothesized mechanisms can be broadly classed into three main ways that organics may appear in the exit gases from combustors:

- Lack of destruction of organics originally present in the feed refuse,
- Conversion of precursors present in the feed or formed in the combustion processes to organic compounds emitted from the stack, and
- Lack of destruction of precursors in the combustion system and conversion of the precursors to other organic substances downstream of the combustion zone at low temperatures.

While it is not certain which, if any, of these basic mechanisms dominates, all three basic formation mechanisms would be minimized by achieving complete combustion, thereby converting all organic species to $CO_2$.

Thermodynamic considerations indicate that under excess air conditions and temperatures characteristic of municipal waste combustors, there is no theoretical barrier to achieving essentially zero emission levels for these species.[17] In spite of this, emission measurements have shown the presence of significant quantities of organic species in exit gases from some municipal waste combustors. Existence of these species (either in the flame or in the exhaust) indicates a failure in the combustion process caused by insufficient mixing and characterized by escape of local fuel-rich pockets of gas. This perplexing formation may be more easily understood when the heterogeneity of municipal refuse is considered. The collection of discarded materials known as municipal refuse forms a highly variable, heterogeneous fuel containing items of all sizes and shapes, composed of all sorts of materials. Solid pieces of the waste may volatilize and/or pyrolyze unevenly, causing fuel-rich pockets of gas to form in the furnace. If these fuel-rich pockets are not sufficiently mixed with air, incomplete combustion will result and organic materials may be emitted to the atmosphere.

However, theoretical kinetic and equilibrium considerations indicate that the destruction of organic species can be rapidly achieved in the presence of sufficient oxygen at elevated temperatures.[17,20] Therefore, control of organic emissions requires development of a combustion control strategy that ensures that all organic materials, down to the molecular level, are exposed to enough air and to a high enough temperature for enough time to destroy them.

Conditions within the municipal waste combustor that would satisfy the above goals are:

- Mixing of fuel and air to prevent the existence of fuel-rich pockets in the combustion gases,
- Sufficiently high temperatures in the presence of sufficient oxygen for destruction of organic species, and
- Prevention of quench zones or low temperature pathways that would allow partially reacted or unreacted fuel from exiting the combustion zone of the furnace.

### 4.1.1 Combustion Controls*

To achieve the thorough combustion required to minimize emissions of organic species, manufacturers of municipal waste combustion equipment are paying a great deal of attention to three combustion parameters: time, temperature, and mixing (turbulence). However, the simplistic view of optimization of combustion by the "three Ts" (time, temperature and turbulence) is not directly valid in this context. For example, the gas phase residence time should not be considered solely a necessary reaction time, but should also be considered a mixing time. Time is required for air and intermediates to mix, but once mixed at sufficient temperature, the destruction reaction takes place virtually instantaneously. There is no need to hold the mixed gases at this temperature for a longer time. Further, turbulence on its own is not sufficient to ensure the necessary mixing. Two separate, highly turbulent stream tubes in the furnace will not mix despite their high turbulence level unless they come into contact. Thus, mixing of the furnace gases with air requires that the turbulent jets be dispersed throughout the combustion gases. Finally, the definition of a mean temperature must be made with the minimum required temperature and expected variability around the mean in mind.

---

*The information presented in this section is a summary of information presented in Reference 17, Municipal Waste Combustion Study: Combustion Control of Organic Emissions.

With the goal of complete combustion in mind the EPA has developed a set of combustion strategy elements termed "good combustion practices." These control strategy elements are summarized in Table 4-2 for mass burn, modular and RDF units, respectively. Also shown are preliminary specifications for each of the elements.

Detailed information concerning the selection of each of these preliminary specifications is presented in the volume titled "Municipal Waste Combustion Study: Combustion Control of Organic Emissions."[17] In general, they were derived from theory and expert opinion. They have been reviewed by EPA; trade and professional organizations such as the American Society of Mechanical Engineers and the American Boiler Manufacturers Association, and others.

Several cautionary notes are associated with these specifications. First, these recommendations are preliminary and have not been verified in field tests. There are no test data that explicitly show the effects of these practices on emissions. Moreover, as with any general principles, the specific designs of individual systems must be considered. In particular, several combustion systems, such as the mass burn refractory technologies of Volund and Enercon/Vicon and the mass burn rotary technology of Westinghouse/O'Connor incorporate differences from the typical of the practices described in Table 4-2. For such systems, parameters such as "fully mixed height" will have to be defined based on technology-specific engineering analysis rather

## TABLE 4-2. GOOD COMBUSTION PRACTICES FOR THE MINIMIZATION OF ORGANIC EMISSIONS FROM MUNICIPAL WASTE COMBUSTORS

| Practice | Mass Burn Preliminary Target | RDF Preliminary Target | Starved-air Preliminary Target |
|---|---|---|---|
| Design temperature at fully mixed height | 1800°F at fully mixed height | 1800°F at fully mixed height | 1800°F at fully mixed height |
| Underfire air control | At least four separately adjustable plenums. One each under the drying and burnout zones and at least two separately adjustable plenums under the burning zone. | As required to provide uniform bed burning stoichiometry | |
| Overfire air capacity (not an operating requirement) | 40% of total air | 40% of total air | 80% of total air |
| Overfire air injector design | That required for penetration and coverage of furnace cross-section | That required for penetration and coverage of furnace cross-section | That required for penetration and coverage of furnace cross-section |
| Auxiliary fuel capacity | That required to meet start-up temperature and 1800°F criteria under part-load operations | That required to meet start-up temperature and 1800°F criteria under part-load operations | That required to meet start-up temperature and 1800°F criteria under part-load conditions |
| Excess Air | 6 - 12% excess oxygen (dry basis) | 3 - 9% excess oxygen (dry basis) | 6 - 12% excess oxygen (dry basis) |
| Turndown restrictions | 80 - 110% of design - lower limit may be extended with verification tests | 80 - 110% of design - lower limit may be extended with verification tests | 80 - 110% of design - lower limit may be extended with verification tests |
| Start-up procedures | On auxiliary fuel to design temperature | On auxiliary fuel to design temperature | On auxiliary fuel to design temperature |
| Use of auxiliary fuel | On prolonged high CO or low furnace temperature | On prolonged high CO or low furnace temperature | On prolonged high CO or low furnace temperature |
| Oxygen in flue gas (continuous monitor) | 6 - 12% dry | 3 - 9% dry | 6 - 12% dry |
| CO in flue gas (continuous monitor) | 50 ppm on 4 hour average - corrected to 12% $CO_2$ | 50 ppm on 4 hour average - corrected to 12% $CO_2$ | 50 ppm on 4 hour average - corrected to 12% $CO_2$ |
| Furnace temperature (continuous monitor) | Minimum of 1800°F (mean) at fully mixed height across furnace | Minimum of 1800°F (mean) at fully mixed height | Minimum of 1800°F (mean) at fully mixed plane (secondary chamber) |
| Adequate air distribution | Verification test* | Verification test* | Verification test* |

*See text in Section 4 and "Municipal Waste Combustion Study: Combustion Control of Organic Emissions," Chapter 9.

than on the general one-meter rule suggested for traditional mass burn systems. However, it is important for permit writers and those applying for permits to be aware of the conditions that promote achievement of complete combustion. Those planning to construct municipal waste combustion facilities should also be aware of good combustion practices and their implications for design practices. For example, one implication of turndown restrictions is design for fairly constant load. Sizing for a fairly constant load becomes a critical part of the design, and load leveling constraints may increase the benefits of designs using multiple combustion units, for example.

Of course, the final determinant of the performance of each system is the measured level of trace organics emitted. Whether these levels indicate acceptable performance will depend on emission levels established in the facility's permits, state standards or guidance, and any federal guidance or regulation that may be established in the future.

Recent test data obtained from the new municipal waste combustor in Tulsa show that low concentrations of organics may be achieved by optimizing combustion conditions even though the design and operating conditions cannot be directly related to the preliminary targets in Table 4-2. Although no post combustion control devices were installed specifically for removal of organic species, the organic concentrations are lower than those measured in any similarly equipped facility, indicating thorough optimization of the combustion process. The only lower values for mass burn units in the EPA's Emissions Data Base were measured in units equipped with alkaline scrubber/fabric filter systems, as discussed in the section on CDD and CDF emissions. In fact, the concentrations of TCDD, TCDF, PCDD, and PCDF were on the same order but lower than the concentrations measured at the Wurzburg facility which is equipped with a dry scrubber/fabric filter system.[16]

Another illustration of the possibility of decreasing organic emissions through combustion optimization is the municipal waste combustor in Quebec. In Quebec, an older facility was modified to reflect current low emission design philosophy. Concentrations of CDD and CDF were measured before and after the modifications as follows:[21]

| | Before | After |
|---|---|---|
| CDD | 800 - 3980 ng/Nm$^3$ | 12 - 205 ng/Nm$^3$ |
| CDF | 100 - 1100 ng/Nm$^3$ | 49 - 336 ng/Nm$^3$ |

These data are preliminary and corrected to 12% $CO_2$. These data indicate the possibility of using a combination of combustion system design and operational tuning to significantly reduce CDD and CDF emissions. However, the specific changes appropriate for a specific facility and the likely effectiveness of those changes in reducing organic emissions must be determined on a case-by-case basis.

An important factor in operation of an optimally designed and tuned municipal waste combustor in a continuously optimized manner is operator training. The Northeast States for Coordinated Air Use Management (NESCAUM) and the American Society of Mechanical Engineers (ASME) have developed a training course for resource recovery facility operators. NESCAUM plans to offer the course in the fall of 1987. In addition, NESCAUM is working with ASME to develop a formal accreditation program for training and certification of operators of resource recovery facilities, to be administered by ASME.[+] Certification of operators has now been included in the requirements for operating permits in Connecticut, New Jersey, New York, and Vermont.

### 4.1.2 Flue Gas Treatment*

The previous discussion has dealt exclusively with destruction of organic materials to minimize organic emissions through design and operation of the combustion process. Control of organic emissions may also be accomplished through post combustion control techniques. In fact, the secondary combustion chambers on many modular combustors can be thought of as afterburners. Although no conventional mass burn facilities employing afterburners have been identified, this type of control device might be used to control organic emissions. Direct flame afterburners operating at 2,000°F for a 1.0 second residence time have demonstrated the ability to achieve greater than

---

[+] Thomas Allen, Associate Director of the Division of Air, New York Department of Environmental Conservation, is the Acting Chairman of the ASME Accreditation Committee. Arlene Spadafino, a Director in ASME's Codes and Standards Division, may be contacted for further information at (212) 705-7030.

*Information presented in this section is summarized from Reference 19, Municipal Waste Combustion Study: Flue Gas Cleaning Technology.

98 percent destruction of hazardous wastes, even for chlorinated organics.[22,23]

Recent tests have indicated that alkaline scrubbing systems can achieve significant control of organic emissions. There are several different types of alkaline scrubbers and the terminology describing them can be confusing. In the United States scrubbers have been classified as either wet or dry, depending on whether the cleaned flue gas leaving the scrubbing system is saturated. Using this classification, a wet scrubbing system emits a saturated gas, while a dry scrubber has a gaseous effluent which is unsaturated. Scrubber terminology in other countries often includes "semi-dry" or "wet/dry" and "dry" scrubber. The terms "semi-dry" and "wet/dry" apply to a spray dryer and fabric filter or ESP system in which the sorbent enters the spray dryer as a slurry or solution and the cleaned flue gas leaves the particulate collector unsaturated. The terms "dry scrubber" or "dry injection", as often used in the same countries, refer to a dry powdered sorbent being injected into the flue gas upstream of the particulate collector. In the United States, scrubbing systems using either spray drying or dry injection of sorbent upstream of particulate collectors are commonly called "dry" scrubbers.

The mechanism of organic pollutant capture by alkaline scrubbers is not clear. It is likely that condensation and capture in the physical form of particulates or aerosols is an important mechanism, but chemical reaction with caustic reagents is also a possibility. To take advantage of these collection phenomena, a control strategy could include steps to lower the flue gas temperature, subject it to caustic sorbents, and collect the particles with an efficient particle collector. Combinations of equipment would be required to implement this strategy; spray drying combined with an ESP or spray drying combined with a fabric filter would be the probable choice. A few data are available showing the effectiveness of the combination of alkaline scrubbing with a fabric filter for control of CDD. Data showing the effectiveness of an alkaline scrubber with an ESP are more limited. Data from two sets of pilot plant tests are shown in Table 4-3. The combination of alkaline scrubbing with fabric filtration also may be used to control emissions of acid gases and metals. This cooperative effect is discussed more fully in the section on multipollutant control strategies.

## TABLE 4-3. CONTROL EFFICIENCY DATA FOR CDD

| | | % Efficiency |
|---|---|---|
| Spray Dryer + ESP[24]<br>reported by manufacturer | | 48 - 89* |
| Spray Dryer + Fabric Filter24<br>tested by manufacturer | High T<br>Low T | 52 - 93*<br>97 - 99.8* |
| Spray Dryer + Fabric Filter[25]<br>Environment Canada | | >99.9 |
| Dry Injection + Fabric Filter[25]<br>Environment Canada | 200°C<br>110° - 140°C | 99.4<br>>99.9 |

*Range for different homologs.

## 4.2 ACID GASES*

Control of acid gases (HCl, HF and $SO_2$) requires scrubbing or devices for gas/liquid or gas/solid contact. Water alone is a reasonably effective sorbent for very reactive acid gases such as HCl and HF, but an alkali sorbent is necessary for substantial $SO_2$ control.

Effective acid gas control is possible with dry, semi-dry and wet scrubbers. HCl and HF are relatively easy to control, while $SO_2$ control is favored by wet or semi-dry systems with lower flue gas temperatures. Alkaline scrubbing systems combined with particulate capture devices may be used to control other pollutants such as some organic species and metals. This synergy is discussed more fully in the section on multipollutant control strategies. Spray drying or semi-dry injection of sorbent is more effective than dry injection of sorbent. The most effective control of acid gases is by wet alkali scrubbers, but wet scrubbing produces waste water that must be treated.

Combination dry, semi-dry scrubbers may control acid gases more effectively than once-through spray drying and may be similar in effectiveness to spray drying with recycle. Combination wet-dry systems may be the most effective system for acid gas control but are increasingly complex. Table 4-4 summarizes the scrubber options for acid gas control and shows expected control efficiencies. It should be noted that any of these techniques may be enhanced by the use of more reactive sorbents or by operation at more favorable temperatures. Table 4-5 shows acid gas control efficiency data included in the EPA's Emissions Data Base. These data are supported with emission test reports (Municipal Waste Combustion Study: Emission Data Base for Municipal Waste Combustors).[16]

---

*Information presented in this section is summarized from Reference 19, Municipal Waste Combustion Study: Flue Gas Cleaning Technology.

## TABLE 4-4. EXPECTED EFFECTIVENESS OF ACID GAS CONTROLS (% REMOVAL)[19]

| Control System | Pollutant |  |  |
|---|---|---|---|
|  | HCl | HF | $SO_2$ |
| Dry Sorbent Injection + Fabric Filter[a] | 80 | 98 | 50 |
| Dry Sorbent Injection + Fluid Bed Reactor/ESP[b] | 90 | 99 | 60 |
| Spray Dryer - ESP | 95+ | 99 | 50 - 70 |
| (Recycle)[c] | (95+) | (99) | (70 - 90) |
| Spray Dryer Baghouse | 95+ | 99 | 70 - 90 |
| (Recycle)[c] | (95+) | (99) | (80 - 95) |
| Spray Dryer + Dry Sorbent Injection + Fabric Filter[d] | 95+ | 99 | 90+ |
| Wet Scrubber[e] | 95+ | 99 | 90+ |
| Dry/Wet Scrubber[e,f] | 95+ | 99 | 90+ |

[a] T = 160 - 180°C. T is the temperature at the exit of the control device.

[b] T = 230°C

[c] T = 140 - 160°C

[d] T = 200°C

[e] T = 40 - 50°C

[f] Consists of a spray dryer which atomizes spent scrubber liquor from two venturi scrubbers, one for HCl control and the other for $SO_2$ control, to dispose of liquid wastes. The venturi scrubbers are in series and follow the particulate control device which is just downstream of the spray dryer. This system, by proper selections of feed stream compositions to the venturis, can also be used for $NO_x$ control.

## TABLE 4-5. CONTROL EFFICIENCY DATA FOR ACID GASES[16]

| Facility | Control Device | Control Efficiency (%) HCl | HF | $SO_2$ |
|---|---|---|---|---|
| Gallatin | Cyclone/fabric filter | | | 0 |
| Kure | ESP/water scrubber | 79 | 68 | 87 |
| Quebec | Dry injection/fabric filter | | | |
| | 110°C | 99 | | 96 |
| | 125°C | 98 | | 92 |
| | 140°C | 93 | | 78 |
| | 200°C | 77 | | 23 |
| | Spray dryer/fabric filter | | | |
| | 140°C | 91 | | 67 |
| | 140°C with recycle | 91 | | 60 |
| Tsushima | Spray dryer/dry injection/fabric filter (Teller system) | 98 | 48 | 99.7 |
| Munich | Dry scrubber/ESP | 95 | | |
| Malmo | Cyclone/dry scrubber/ESP/fabric filter | 72 | | |

## 4.3 NITROGEN OXIDES

Control of nitrogen oxides may be accomplished through post-combustion flue gas treatment processes. Selective catalytic reduction (SCR) is the most advanced process. In the selective catalytic reduction process $NO_x$ is reduced to nitrogen and water vapor with the addition of ammonia in the presence of a catalyst. Although not specifically applied to municipal waste combustion, SCR is being applied to sludge combustors in Japan and the technology is expected to be readily transferable.

Impurities such as HCl and metals degrade the SCR catalyst, so municipal waste combustor gases are typically subjected to cleaning processes before they contact the special titanium-based honeycomb catalyst system. Design data show 80 to 90 percent reduction of $NO_x$, but performance data are unavailable.

Another $NO_x$ control system, thermal $DeNO_x$, involves injection of ammonia in the upper furnace to achieve selective reduction of $NO_x$. This system is currently installed on at least one municipal waste combustor in California. The effects of thermal $DeNO_x$ systems on other pollutants in the flue gas from municipal waste combustors have not been established.

## 4.4 PARTICULATE MATTER*

Control of particulate matter emissions is currently practiced to a large extent among existing municipal waste combustors. Electrostatic precipitators (ESPs), fabric filters, and wet scrubbers are all systems used to control particulate matter emissions. Newer units are equipped with ESPs and fabric filters. Modern ESPs can achieve very high removal efficiencies for particulate matter (>99%). There are currently nearly 40 U.S. municipal waste combustion facilities equipped with ESPs, some of which are combined with other flue gas treatment technologies. Also, a trend can be seen toward higher particulate matter collection efficiencies with newer installations.

---

*Information presented in this section is summarized from Reference 19, Municipal Waste Combustion Study: Flue Gas Cleaning Technology.

Fabric filters have not generally been applied directly to flue gas from municipal waste combustors, but they have been used as sorbent collectors and secondary reactors for dry and semi-dry scrubbers. Three reasons that fabric filters have not been applied directly to municipal waste combustor flue gas are: (1) attack by acid gases upon fabric, (2) fabric blinding by "sticky" particles, and (3) baghouse fires caused by unstable combustion and carryover of sparks into the flue. Electrostatic precipitators and wet scrubbers are somewhat more forgiving of these phenomena and have generally been preferred. However, upstream scrubbing of acid gases with sorbent accumulation on fabric materials can address the problems mentioned above, so that fabric filters become an attractive choice for control of particulate matter emissions. Fabric filters used in this way with upstream sorbent injection are capable of particulate matter control to concentrations of less than 0.02 gr/dscf.

Wet scrubbers are not likely to be applied to municipal waste combustors for control of particulate matter emissions in the future. Although wet scrubbers account for nearly one-fifth of existing particulate matter control systems in the United States, they have disadvantages which are likely to eliminate them from future selection. First, used alone, without additional particulate matter controls, they are not as effective in controlling particulate matter as other control equipment. It is unlikely that wet scrubbers can meet current or future particulate matter emission requirements without very high pressure losses accompanied by erosion and increased maintenance requirements. Second, wet scrubbers will absorb acid gases including HCl and, if they are not designed to handle the accumulating acids, will have significant operating problems.

Efficient particulate matter capture devices also provide enhanced capture of other pollutants in the flue gas in solid or aerosol form, e.g., metals and large organic molecules. These captured materials then become part of the ash residue from the process.

## 4.5 METALS

Effective control of particles and low flue gas temperatures are major factors in the control of metals emissions. Sorbents are not suspected of playing a major role. Nevertheless, scrubber systems combined with particulate control devices have achieved effective metals removal because they cool the incoming flue gas. Metals and metallic compounds enter the combustor in the solid waste material and are not destroyed in the combustion process, although they may change phase or react to form other metallic compounds. Because they are not destroyed, they must leave the combustion process in the bottom ash, fly ash, or stack gas. Metals and metallic compounds carried by the flue gas enter particulate matter collectors as solids, liquids, and vapors, and as the flue gas cools, the vapor portion converts to collectible solids and liquids.

Based on theoretical vapor pressure considerations, reduction of flue gas temperatures to below 200°C (392°F) in combination with high efficiency particulate collection should result in 99 percent reduction of metals, except for mercury (Hg), arsenates $(AsO_4)^{-3}$, and selenium ($SeO_2$ and $Se_6$). Increased reduction in concentrations of these compounds occurs as temperatures are increasingly lowered.

Recently collected metals data from a pilot-scale test in Quebec are summarized in Table 4-6. The inlet and outlet concentrations data show that the alkaline scrubber/fabric filter system effected greater than 99.9% removal efficiency for all metals except mercury. The collection efficiency for mercury ranged from 91 to 97 percent except for the high temperature (209°C) test in which a negative control efficiency was measured. Environment Canada characterized this result as indicative of no mercury removal. It is also important to note that measurements of metals in the ash residues showed that the solids collected by the fabric filter were enriched with metals.[25] The fabric filter solids contained by far the highest concentration and the highest quantities of total metals.

In other tests, metals control efficiency data show 95-98 percent control or greater for heavy metals except mercury. Seventy-five to 85 percent control of mercury vapor has been reported with a spray dryer combined with a baghouse; 35 to 45 percent control has been reported with a spray dryer plus ESP.

## TABLE 4-6. INLET/OUTLET METAL CONCENTRATIONS FROM QUEBEC PILOT PLANT TESTING (ug/$Nm^3$ @ 8% $O_2$)[25]

| | | Dry Injection | | | | Spray Dryer | |
|---|---|---|---|---|---|---|---|
| Metal | Location | 110°C[a] | 125°C[a] | 140°C | >200°C | 140°C | 140°C +Recycle |
| Zinc | Inlet | 99,000 | 108,000 | 93,000 | 91,000 | 77,000 | 88,000 |
| (Zn) | Outlet | 7 | 5 | 6 | 10 | 5 | 6 |
| Cadmium | Inlet | 1,300 | 1,300 | 1,500 | 1,000 | 1,200 | 1,100 |
| (Cd) | Outlet | 0.4 | 0.4 | ND | 0.6 | ND | ND |
| Lead | Inlet | 41,000 | 44,000 | 34,000 | 35,000 | 36,000 | 34,000 |
| (Pb) | Outlet | 4 | 3 | 5 | 6 | 1 | 6 |
| Chromium | Inlet | 3,100 | 1,900 | 2,000 | 1,900 | 1,400 | 1,700 |
| (Cr) | Outlet | 0.4 | 0.4 | 1 | 0.5 | 0.2 | 0.7 |
| Nickel | Inlet | 1,000 | 1,800 | 1,300 | 800 | 700 | 2,500 |
| (Ni) | Outlet | 1.3 | 0.4 | 0.7 | 2 | 1.3 | 2 |
| Arsenic | Inlet | 150 | 100 | 130 | 80 | 110 | 130 |
| (As) | Outlet | 0.02 | 0.04 | 0.04 | 0.07 | 0.04 | 0.03 |
| Antimony | Inlet | 2,000 | 800 | 1,000 | 1,500 | 1,000 | 2,200 |
| (Sb) | Outlet | 0.2 | 0.4 | 0.6 | 0.5 | 0.3 | 0.6 |
| Mercury | Inlet | 440 | 480 | 320 | 450[b] | 190 | 360 |
| (Hg) | Outlet | 40 | 13 | 20 | 610 | 10 | 19 |

Note: Concentrations rounded off for simplicity.

ND = Not detected

[a] Based on one test run, except for mercury, which is based on two test runs.

[b] Negative control efficiency; no capture of mercury occurred.

## 4.6 MULTIPOLLUTANT CONTROL STRATEGIES

In devising a control strategy for minimizing emissions to the atmosphere from municipal waste combustors, a starting place is alteration of design or operating practices that may cause or exacerbate pollutant formation; i.e., combustion controls. With the potential for pollutant formation in the process minimized, the next logical step would be the use of post combustion flue gas cleaning equipment to remove remaining pollutants from the flue gases. However, this straightforward approach is complicated because the control problem consists of many different pollutants emitted together, so the effects of the various control options on other pollutants must be considered.

In the previous discussion on control options, the potential for minimizing organic emissions through a combustion optimization strategy was presented. The combustion strategy may do little for the control of other pollutants, however. In fact, while combustion optimization is expected to have little impact on acid gases and particulate matter, it may increase emissions of $NO_x$ and some metals.

The preliminary combustion control strategy is probably most incompatible with $NO_x$ emissions minimization. High-temperature, well-mixed, excess air conditions favor the formation of $NO_x$ from both thermal fixation of molecular nitrogen and the conversion of fuel nitrogen. Traditionally, $NO_x$ emissions from municipal waste combustors have not been controlled, and the need to control $NO_x$ emissions has been confined to fairly localized areas. As previously pointed out, $NO_x$ emissions can be reduced by flue gas cleaning processes. It is not clear what effect $NO_x$ control systems may have on other pollutants, but they are not expected to provide significant removal potential for other pollutants.

Metal concentrations in uncontrolled stack gases may also be exacerbated by the recommended combustion strategy. The partitioning of metals among bottom ash, fly ash, and the gas phase depends on the temperature and oxygen levels experienced by the metal-bearing refuse. For example, higher air velocities through the bed will increase the entrainment of particles. Also, changes in stoichiometry for proper air distribution will influence the vaporization of volatile metals. And, temperature increases favor the vaporization of volatile metals. As in the case with $NO_x$ control, metal emissions may also be removed in flue gas cleaning processes.

High efficiency particulate collection devices, such as ESPs and fabric filters, have the potential for collection of metals and organics that exist in the stack gases in particulate or aerosol form. Furthermore, when combined with cooling to promote condensation, this collection potential is further enhanced. Adding to these possible processing steps, the use of alkali sorbents enhances the collection still further by increasing the potential for collecting organic materials such as CDD and CDF and acid gases.

An approach to minimizing a whole list of emissions to the atmosphere from municipal waste combustors would be:

- optimization of the combustion process,
- flue gas treatment using alkaline scrubbers in conjunction with ESPs or fabric filters at a temperature conducive to promoting condensation, and
- flue gas treatment for $NO_x$ control, if necessary.

With respect to cooling the stack gases, there are practical limits with the use of ESPs alone. Very low exit temperatures may not be feasible without additional gas conditioning because of acid condensation and corrosion problems. To operate with low exit gas temperatures, it may be necessary to use an alkaline scrubber upstream of an ESP.

Testing of control equipment designed for multipollutant control is now beginning and results are just becoming available. Tables 4-7, 4-8 and 4-9 contain summary results of such emissions testing. The first table is a very simplified representation of an extensive series of tests performed by Environment Canada at Quebec. Tests were performed at a pilot plant by testing control device efficiency on a slip stream from a commercial-scale municipal waste combustor. Tests were run at several flue gas temperatures on two scrubbing systems, dry lime injection/fabric filter and lime spray dryer/fabric filter. In general, high removal efficiencies were seen in both systems for all pollutants of concern, but cooling of the flue gas below 200°C was seen as key to the control of hydrogen chloride, sulfur dioxide, and mercury.[25]

## TABLE 4-7. SUMMARY OF TESTING OF MULTIPOLLUTANT CONTROL STRATEGY AT QUEBEC CITY[25]

| Pollutant | Range of Removal Efficiencies Measured (%) |
|---|---|
| PCDD | 99.4 to > 99.9 |
| PCDF | 99.3 to > 99.9 |
| Chlorobenzenes | 62[a] to > 99 |
| Polychlorinated biphenyls | 54[a] to > 99 |
| Polycyclic aromatic hydrocarbons | 79[b] to > 99 |
| Chlorophenols | 56[a] to 99 |
| Zinc | > 99.9 |
| Cadmium | > 99.9 |
| Lead | > 99.9 |
| Chromium | > 99.9 |
| Nickel | > 99.9 |
| Arsenic | > 99.9 |
| Antimony | > 99.9 |
| Mercury | 0[a] to 97 |
| Hydrogen Chloride | 77[a] to 98 |
| Sulfur dioxide | 29[a] to 96 |

[a] Measured at highest test temperature (209°C)

[b] Measured in recycle test.

TABLE 4-8. SUMMARY OF TESTING OF MULTIPOLLUTANT CONTROL STRATEGY PERFORMED BY NIRO[26]

| Pollutant | Emissions Data |
|---|---|
| Particulate matter | 5 to 10 $mg/Nm^3$ |
| HCl | 5 to 15 $mg/Nm^3$ |
| HF | 0.3 $mg/Nm^3$ |
| $SO_2$ | 20 to 70 $mg/Nm^3$ |
| $SO_3$ | 1 $mg/Nm^3$ |
| Cd | 0.01 to 0.03 $mg/Nm^3$ |
| Hg | 0.03 to 0.1 $mg/Nm^3$ |
| Dioxins/furans | 90 to 99% removal |

## TABLE 4-9. COMPARISON OF PILOT-SCALE TESTS OF MULTIPOLLUTANT CONTROL EQUIPMENT[18]

| Pollutant | Pollutant Removal Efficiency | |
|---|---|---|
| | Spray dryer/ESP | Spray dryer/ fabric filter |
| Hg[a] | 35 - 40% | 75 - 85% |
| Pb | 65 - 75% | 95 - 98% |
| Cd | 95 - 97% | 95 - 97% |
| As | 93 - 98% | 95 - 98% |
| Particulate Matter | >99% | >99% |
| CDD | 48 - 89% | >99%[b] |
| CDF | 64 - 85% | >99%[b] |

[a] Vapor only

[b] At 110°C

The second table contains data provided by Niro atomizer on their spray dryer combined with a "dust collector."[16] Table 4-9 shows results of pilot-scale testing of a spray dryer/ESP system and a spray dryer fabric filter system.[18] Results of additional tests of these multipollutant control systems are now being released and will provide additional information with which they may be evaluated.

# 5. IMPACTS OF POTENTIAL CONTROL STRATEGIES

A major concern voiced by the public in communities where municipal combustors are being considered is the health risk from emissions of pollutants to the atmosphere. In the following analysis, health risks due to direct inhalation of pollutants and due to other indirect exposure routes are discussed for the existing and the projected future combustor populations, under two different levels of pollution control. Costs and other effects are also considered.

## 5.1 ESTIMATED HEALTH RISK UNDER TWO CONTROL SCENARIOS

The risk analysis seeks to answer the questions of what are the health risks associated with municipal waste combustion, and how might they be reduced by applying emission controls? To address these questions, EPA analyzed exposures to pollutants directly emitted to the atmosphere from municipal waste combustors and indirect exposures from deposited pollutants. Health risks from carcinogens and non-carcinogens were considered. And, to capture the risk from municipal waste combustors as they exist today and as they may exist in the future, the risk analysis was extended to the projected population. Thus, the analysis consists of many parts defined by route of exposure, combustor population, emission control scenario, and the type of health effect being considered. Results of these risk analysis elements were generated for several organic pollutants (CDD, CDF, chlorophenols, chlorobenzenes, formaldehyde, polychlorinated biphenyls, polycyclic aromatic hydrocarbons) and for inorganic pollutants (arsenic, beryllium, mercury, lead, cadmium, and hexavalent chromium, and hydrochloric acid).

### 5.1.1 Methodology

The methodology for performing this complex analysis is described in detail in "Municipal Waste Combustion Study: Assessment of Health Risks Associated with Municipal Waste Combustion Emissions."[27] In its evaluation of the potential health risks from combustion sources, EPA traditionally has focused on air emissions from the source and on the carcinogenic risks from direct inhalation of predicted ambient air concentrations of pollutants. The risk analysis for municipal waste combustors represents an expansion of the analytical scope to include consideration of multiple exposure pathways, carcinogenic and non-carcinogenic risks posed to humans, and potential adverse effects to the natural environment.

5.1.1.1 Emissions and Control Scenarios. The risk analysis was constructed to include existing and projected combustors under a baseline control scenario and a controlled scenario. The baseline scenario was designed to reflect the status quo in add-on control technology (ESPs), while the controlled scenario was designed to reflect uniform application of dry scrubbing combined with very efficient particulate collection devices. In terms of combustion efficiency the models assumed existing units under both control scenarios would have combustion efficiencies reflective of currently operating combustors. The projected population, however, was assumed to incorporate very efficient combustion under both control scenarios.

The existing and projected populations of combustors used in the risk analysis are described in "Municipal Waste Combustion Study: Characterization of the Municipal Waste Combustion Industry."[6] Since the risk analysis and the development of the emissions data base proceeded in parallel, emissions estimates were developed from test data compiled and presented in a publicly released draft of the volume titled "Municipal Waste Combustion Study: Emission Data Base for Municipal Waste Combustors. (January 1987)"[37] Tables 5-1 and 5-2 indicate from which units test data were derived. Details about the facilities tested and testing procedures used to generate the emissions test data also may be found in the EPA's Emissions Data Base[16,37]. For each pollutant, emissions data from the facilities listed in the tables were averaged to obtain an overall emission factor.

As the tables show, for some pollutants the emissions estimates are based on very little data, especially for the organic pollutants. Another observation from Table 5-2 is the different lists of facilities chosen to represent existing and planned facilities. An attempt was made to use the *most appropriate* data to represent emissions from different types of

## TABLE 5-1. METALS EMISSION FACTOR DATA SUMMARY

| POLLUTANT METALS | FACILITY TYPE | MWC FACILITIES TESTED |
|---|---|---|
| Arsenic | MB Water Wall | Baltimore, Braintree, Hampton, Munich, Wurzburg |
| | MB Refractory | Tsushima |
| | RDF | Akron, Albany |
| | Modular | Tuscaloosa, Dyersburg, Prince Edward Island |
| Beryllium | MB Water Wall | Braintree, Hampton, Tulsa, Munich |
| | MB Refractory | Tsushima |
| | RDF | Albany |
| | Modular | Dyersburg |
| Cadmium | MB Water Wall | Braintree, Hampton, Munich, Malmo, Wurzburg |
| | MB Refractory | Washington, Alexandria, Nicosia, Tsushima |
| | RDF | Albany |
| | Modular | Dyersburg, Prince Edward Island |
| Chromium | MB Water Wall | Baltimore, Braintree, Hampton, Munich, Wurzburg |
| | MB Refractory | Washington, Alexandria, Nicosia, Tsushima |
| | RDF | Akron, Albany |
| | Modular | Dyersburg, Prince Edward Island |
| Lead | MB Water Wall | Braintree, Hampton, Tulsa, Munich, Malmo, Wurzburg |
| | MB Refractory | Washington, Alexandria, Nicosia, Tsushima |
| | RDF | Akron, Albany |
| | Modular | Dyersburg, Prince Edward Island |
| Mercury | MB Water Wall | Braintree, Hampton, Tulsa, Malmo |
| | MB Refractory | Tsushima |
| | RDF | Akron, Albany |
| | Modular | Dyersburg, Prince Edward Island |
| Nickel | MB Water Wall | Hampton, Munich, Wurzburg |
| | MB Refractory | Washington, Alexandria, Nicosia, Tsushima |
| | RDF | Akron, Albany |
| | Modular | Dyersburg, Prince Edward Island |

## TABLE 5-2. MUNICIPAL WASTE COMBUSTION FACILITIES FROM WHICH TEST DATA WERE USED FOR ORGANIC EMISSION FACTORS

| # | MWC Tested | CDD/CDF | B(a)P | PCB | Formaldehyde | Chlorobenzenes | Chlorophenols |
|---|---|---|---|---|---|---|---|
| EXISTING MWC | | | | | | | |
| 1 | Mass Burn Non Heat Recovery | Philadelphia NW | Hampton | Hampton | Hampton<br>Peekskill | Chicago NW<br>Hampton | Chicago NW<br>Hampton |
| 6 | Mass Burn Heat Recovery | Quebec<br>Saugus<br>Chicago<br>Peekskill<br>Tulsa<br>Hampton<br>N. Andover | Hampton | Chicago NW<br>Hampton | Hampton<br>Peekskill | Chicago NW<br>Hampton | Chicago NW<br>Hampton |
| 6 | Modular | PEI, Dyersburg<br>N. Little Rock<br>Mayport, Oneida<br>Cattaraugus | Cattaraugus | PEI<br>Cattaraugus | Dyersburg<br>Cattaraugus | PEI | PEI |
| 5 | RDF | Swaru<br>Akron<br>Wright Patterson<br>Albany<br>Niagara Falls | Albany | Albany<br>Swaru | Albany<br>Akron<br>Niagara Falls | Wright Patterson<br>Swaru | Wright Patterson<br>Swaru |
| PROJECTED MWC | | | | | | | |
| 7 | Mass Burn | Wurzburg<br>N. Andover<br>Saugus<br>Peekskill<br>Tulsa<br>Marion Co. | Hampton | Chicago NW | Peekskill | Chicago NW | Chicago NW |
| 5 | RDF | Swaru[a]<br>Akron<br>Wright Patterson<br>Albany<br>Niagara Falls | Albany | Albany<br>Swaru[a] | Albany<br>Akron<br>Niagara Falls | Wright Patterson<br>Swaru[a] | Wright Patterson<br>Swaru |
| 6 | Modular | PEI, Dyersburg<br>N. Little Rock<br>Mayport, Oneida<br>Cattaraugus | Cattaraugus | PEI<br>Cattaraugus | Dyersburg<br>Cattaraugus | PEI | PEI |

[a] Adjusted to reflect judgment about recent modifications.

combustors and for different scenarios. Some of the existing facilities, for example Hampton (mass burn), may not represent performance levels expected of new facilities. Test data from this facility were, therefore, excluded when computing average emission factors for CDD and CDF for the projected population of mass burn heat recovery facilities. For some other organic pollutants, for example B(a)P, there were no state-of-the-art data available, so the data from Hampton were used, even though they may not be considered representative of new facilities. The paucity of data introduces considerable uncertainty, because there is significant variation among emissions measured at different facilities. The variability is due in part to differences in feed materials and design and operating characteristics of municipal waste combustors and air pollution control equipment.

Control efficiencies for the baseline and controlled scenarios were developed as follows. For the existing combustor population, the baseline scenario organic emissions estimates are reflective of uniform use of ESPs because test data were collected from ESP-controlled units. A variety of particulate matter emission controls, however, are actually used at existing facilities. (See Table 5-3.) The baseline scenario for existing units incorporates particulate matter and metals control efficiencies reflective of actual particulate matter control devices in use. The controlled scenario for existing combustors was constructed by assuming 99.5% control of particulate matter emissions, including metals, and 95 percent control of organic emissions. HCl emissions were assumed controlled by 90 percent, and $SO_2$ was assumed controlled by 70 to 90 percent. These control levels reflect the efficiencies achieved by the combination of dry scrubbers and fabric filters tested at pilot-scale facilities by Environment Canada and others. (See Municipal Waste Combustion Study: Flue Gas Cleaning Technology.[19])

For the projected population, control efficiencies for the baseline scenario were assumed to be 20 percent for organics and 99 percent for particulate matter and metals, reflecting application of particulate matter controls only. This is a conservative assumption for organics because many planned facilities are expected to incorporate dry scrubbers, as in the controlled scenario. Little data are available on the performance of ESPs alone in controlling organics. However, preliminary results from recent tests indicate a range of 0 to 50 percent for control of CDD and CDF, and data from

TABLE 5-3. EMISSION CONTROLS ON EXISTING SOURCES

| TECHNOLOGY (# FACILITIES) | COMBUSTION CONTROLS GOOD/FAIR/POOR | FLUE GAS TREATMENT CONTROLS | | | | | |
|---|---|---|---|---|---|---|---|
| | | WET SCRUBBER | ESP | FABRIC FILTER | DS/FF | OTHER | NONE |
| MASS BURN (45) | Good-Poor<br>Many older units are deficient in design, operation, and maintenance | 9 | 33 | 1 | 2 | - | - |
| REFUSE DERIVED FUEL (10) | Not well understood | 1 | 9 | - | - | - | - |
| MODULAR (56) | Good-Fair<br>- starved air<br>- secondary combustion | 4 | 10 | 3 | - | 3 | 36 |

earlier tests at the Chicago NW facility indicated approximately 20 percent control of chlorophenols. In consideration of these limited data points, 20 percent control was assumed. Particulate matter control of 99 percent efficiency reflects the performance of a modern ESP. However, it is possible that some facilities may consider control devices designed to meet current standards of 95% for municipal waste combustors or about 97 to 98 percent for industrial boilers. No control of HCl by ESPs was assumed.

Control efficiencies for the controlled scenario were assumed to be the same as for the existing facility population: 99.5 percent for particulate matter including metals, 95 percent for organics, and 90 percent control of HCl and 70 to 90 percent control of sulfur oxides. This scenario is reflective of uniform application of dry scrubbers and particulate matter control devices to the entire population.

5.1.1.2 Exposure Modeling. Exposure potential due to the direct inhalation route was modeled using EPA's Human Exposure Model[28], which links a dispersion model and population data to estimate exposure levels. Deposition of pollutants was modeled using the ISC-ST model.[29] The Terrestrial Food Chain, Surface Runoff, Groundwater and Dermal Exposure models have been developed to analyze possible human exposure associated with indirect exposure pathways for the deposited emissions. Potential exposure to terrestrial and aquatic organisms exposed to deposited municipal waste combustion emissions have also been addressed in the indirect exposure modeling.

The actual locations and sizes of the facilities were used to model direct inhalation exposure from the existing population. For the projected facilities, two different sets of model facilities were used to project maximum individual risks and annual incidence.

Maximum individual risk estimates were obtained from modeling 3000 ton per day mass-burn, 3000 ton per day RDF, and 250 ton per day modular units. These units were located in urban and suburban areas and represent large planned facilities. From these results, the maximum modeled individual lifetime risk was estimated for projected facilities.

To estimate annual incidence from projected sources, risk estimates were obtained using average-sized model plants of 1000 ton per day mass-burn and 1500 ton per day RDF facilities, each located in hypothetical urban and suburban locations. The average values for the urban and suburban estimates were then scaled up in proportion to the capacity projected for each type of technology in 1993. Risk estimates were also obtained from a 250 ton per day modular facility in two semi-rural locations, and a similar procedure was used to scale up the estimates.

Given the complexities involved in modeling both the environmental fate and transport of specific emitted chemicals and the multiple routes of indirect human exposure to specific chemicals, it is currently not practical to analyze the indirect exposure due to every existing or planned municipal waste combustor. The analysis instead was designed to test the hypothesis of whether indirect exposure routes could contribute significantly to the total exposure due to municipal waste combustors. To examine this possibility, reasonable worst case estimates of long-term indirect exposure were compared against reference levels for health effects. These reference levels are based on either carcinogenic risk or "Risk Reference Doses" (RfDs). The methodology used to analyze indirect exposures evaluated a facility using technologies thought to be representative of those being planned, but under reasonable worst-case environmental conditions in which hydrogeological and meteorological factors combine to enhance the opportunity for exposure. The methodology also evaluated a facility thought to represent worst-case emissions from existing facilities. The methodology evaluated long term deposition and included exposure scenarios over 30 years and over 100 years.

5.1.1.3 Risk Measures. Two types of health risk were addressed: carcinogenic health effects and non-carcinogenic health effects. Unit risk factors representing the lifetime (70 year) upper limit estimate of cancer risk for an individual continuously exposed to 1 ug/$m^3$ of a particular pollutant over 70 years, developed by EPA's Carcinogen Assessment Group were used to estimate the risk of cancer. Cancer risks have been expressed both in terms of annual cancer incidence to the entire exposed population, and risk to a hypothetical individual or subpopulation exposed to the highest modeled ambient levels of each pollutant in the nation - the maximum individual lifetime cancer risk. Risks from exposure to carcinogens were considered additive in conformance with EPA guidelines. Non-carcinogenic health effects were evaluated by comparison with concentrations predicted in the environment to established Risk Reference Dose values for the pollutants.

5.1.1.4 Assumptions. In the previous methodology discussion several uncertainties and assumptions have been noted. In addition, there are a few other points to note about the risk analysis. Risk estimates are based on calculations incorporating a cancer potency estimate and exposure estimate. The estimate of cancer potency is based on a conservative extrapolation of the results of epidemiological studies and studies with laboratory animals. The exposure estimate is based on mathematical models of pollutant dispersion. While both of these approaches are traditionally used in risk calculations, each incorporates uncertainties and assumptions.

Emissions have been modeled as a constant rate over long periods of time. Implicit in this assumption is that average emission levels are equal to those found in the reported tests; therefore, these estimates do not reflect what may occur during start-up, shutdown, or upset conditions. Furthermore, the risk estimates for direct inhalation assume that persons are continually exposed to pollutants for 70 years, and that the population is constant and fixed.

### 5.1.2 Risks from Direct Inhalation

The risk estimates from direct inhalation exposure are shown in Tables 5-4 through 5-6. Tables 5-4 and 5-5 show cancer risk estimates for the direct inhalation route of exposure, disaggregated into risk estimated from metals and organics. Table 5-4 shows risk under the baseline control scenario, while Table 5-5 shows risk under the controlled scenario, as discussed in Section 5.1.1. Table 5-6 shows the contribution to risk made by the individual species modeled.

5.1.2.1 Ranges and Uncertainties. The risk ranges shown in the tables reflect several areas of uncertainty in the analysis. First, recovery of CDD/CDF from the Modified Method 5 stack sampling trains in some cases has been reported to be as low as 10 percent. Thus, actual emission levels could be higher than reported emissions by an order of magnitude. However, recovery has also been reported to be significantly higher. The ranges shown incorporate recovery levels of 10 to 100 percent to account for variation in sampling methods.

## TABLE 5-4. ESTIMATED CANCER RISK FROM INHALATION NATIONWIDE[e]
## (Baseline Scenario)

| | Organics[a] | | Metals[b] | | Combined | |
|---|---|---|---|---|---|---|
| | Ann. Incid.[c] | Max. Indiv.[d] | Ann. Incid. | Max. Indiv. | Ann. Incid. | Max. Indiv. |
| Existing Sources (1985) | | | | | | |
| Mass Burn (Non-heat) | 1 - 30 | $10^{-4}$ - $10^{-3}$ | .2 | $10^{-5}$ | 1 - 30 | $10^{-4}$ - $10^{-3}$ |
| Mass Burn (Heat Rec) | .2 - 4 | $10^{-4}$ - $10^{-3}$ | .04 | $10^{-4}$ | .2 - 4 | $10^{-4}$ - $10^{-3}$ |
| RDF | .1 - 3 | $10^{-5}$ - $10^{-3}$ | .2 | $10^{-5}$ | .3 - 3 | $10^{-5}$ - $10^{-3}$ |
| Modular | .0008-.01 | $10^{-6}$ - $10^{-4}$ | .01 | $10^{-4}$ | .01 - .02 | $10^{-4}$ - $10^{-4}$ |
| EXISTING TOTAL[f] | 2 - 40 | $10^{-4}$ - $10^{-3}$ | .5 | $10^{-4}$ | 2 - 40 | $10^{-4}$ - $10^{-3}$ |
| Projected Sources (1993) | | | | | | |
| Mass Burn (Heat Rec) | .3 - 7 | $10^{-6}$ - $10^{-5}$ | .3 | $10^{-6}$ | .6 - 7 | $10^{-6}$ - $10^{-5}$ |
| RDF | .8 - 10 | $10^{-5}$ - $10^{-4}$ | .1 | $10^{-7}$ | .9 - 10 | $10^{-5}$ - $10^{-4}$ |
| Modular | .04 - .9 | $10^{-6}$ - $10^{-5}$ | .01 | $10^{-6}$ | .05 - .9 | $10^{-6}$ - $10^{-5}$ |
| PROJECTED TOTAL[f] | 1 - 20 | $10^{-5}$ - $10^{-4}$ | .4 | $10^{-6}$ | 2 - 20 | $10^{-5}$ - $10^{-4}$ |
| COMBINED TOTAL[f] | 3 - 60 | $10^{-4}$ - $10^{-3}$ | .9 | $10^{-4}$ | 4 - 60 | $10^{-4}$ - $10^{-3}$ |

---

[a] CDD, chlorophenols, chlorobenzenes, formaldehyde, PCB, PAH. Risk ranges for organics result from assumptions about the carcinogenicity of pollutants classes and the recovery efficiency for CDD/CDF in stack tests.

[b] Arsenic, beryllium, cadmium, chromium +6

[c] Annual incidence is the modeled number of cancer cases per year in populations within 50 km of all municipal waste combustors in the U.S.

[d] Maximum individual risk is the modeled probability that a person exposed to the highest modeled concentration of pollutants from a municipal waste combustor will develop cancer over his or her 70-year lifespan.

[e] Rounded to one significant figure. See text for assumptions involved in producing these estimates.

[f] Totals do not add due to rounding.

## TABLE 5-5. ESTIMATED CANCER RISK FROM INHALATION NATIONWIDE[f]
## (Controlled Scenario)[c]

| | Organics[a] | | Metals[b] | | Combined | |
|---|---|---|---|---|---|---|
| | Ann. Incid.[d] | Max. Indiv.[e] | Ann. Incid. | Max. Indiv. | Ann. Incid. | Max. Indiv. |
| Existing Sources (1985) | | | | | | |
| Mass Burn (Non-heat) | .08 - 2 | 10-5 - $10^{-4}$ | .05 | $10^{-6}$ | .1 - 2 | $10^{-5}$ - $10^{-4}$ |
| Mass Burn (Heat Rec) | .01 - .3 | $10^{-5}$ - $10^{-4}$ | .01 | $10^{-6}$ | .02 - .3 | $10^{-5}$ - $10^{-4}$ |
| RDF | .01 - .2 | $10^{-6}$ - $10^{-5}$ | .03 | $10^{-6}$ | .04 - .2 | $10^{-6}$ - $10^{-5}$ |
| Modular | <.00001 | $10^{-7}$ - $10^{-6}$ | .001 | $10^{-6}$ | .001 | $10^{-6}$ |
| EXISTING TOTAL[g] | .1 - 3 | $10^{-5}$ - $10^{-4}$ | .1 | $10^{-6}$ | .2 - 3 | $10^{-5}$ - $10^{-4}$ |
| Projected Sources (1993) | | | | | | |
| Mass Burn (Heat Rec) | .02-.4 | $10^{-7}$ - $10^{-6}$ | .2 | $10^{-6}$ | .2 - .6 | $10^{-6}$ |
| RDF | .05 - .9 | $10^{-6}$ - $10^{-5}$ | .04 | $10^{-6}$ | .09 - .9 | $10^{-6}$ - $10^{-5}$ |
| Modular | .001-.04 | $10^{-7}$ - $10^{-6}$ | .001 | $10^{-6}$ | .01 - .03 | $10^{-6}$ |
| PROJECTED TOTAL[g] | .07-1 | $10^{-7}$ - $10^{-6}$ | .2 | $10^{-6}$ | .3 - 1 | $10^{-6}$ |
| COMBINED TOTAL[g] | .2 - 4 | $10^{-5}$ - $10^{-4}$ | .3 | $10^{-6}$ | .5 - 4 | $10^{-5}$ - $10^{-4}$ |

---

[a] CDDs, chlorophenols, chlorobenzenes, formaldehyde, PCB, PAH. Risk ranges for organics result from assumptions about the carcinogenicity of pollutant classes and the recovery efficiency for CDD/CDF in stack tests.

[b] Arsenic, beryllium, cadmium, chromium +6

[c] 20% control organics with ESP, 95% with DS/FF

[d] Annual incidence is the modeled number of cancer cases per year in population within 50 km of all municipal waste combustors in the U.S.

[e] Maximum individual risk is the modeled probability that a person exposed to the highest modeled concentration of pollutants from a municipal waste combustor will develop cancer over his or her 70-year lifespan.

[f] Rounded to one significant figure. See text for assumptions involved in producing these estimates.

[g] Totals do not add due to rounding.

## TABLE 5-6. CONTRIBUTION OF INDIVIDUAL POLLUTANTS TO THE ESTIMATED CANCER RISK[c]

| Pollutant | Existing MWC Annual Cancer Incidence[a] | Existing MWC Maximum Individual Risk Range[b] | Projected MWC Annual Cancer Incidence[a] | Projected MWC Maximum Individual Risk Range[b] |
|---|---|---|---|---|
| Chlorinated dioxins and dibenzofurans | 2 to 40 | $10^{-6}$ to $10^{-3}$ | 0.8 to 20 | $10^{-6}$ to $10^{-4}$ |
| Chlorophenols | 0.0001 to 0.0003 | $10^{-9}$ to $10^{-8}$ | 0.0001 to 0.0003 | $10^{-10}$ to $10^{-9}$ |
| Chlorobenzenes | 0.009 to 0.02 | $10^{-7}$ to $10^{-6}$ | 0.004 to 0.01 | $10^{-9}$ to $10^{-7}$ |
| Formaldehyde | 0.009 | $10^{-8}$ | 0.02 | $10^{-8}$ to $10^{-7}$ |
| Polycylic aromatic hydrocarbons | 0.01 to 0.6 | $10^{-7}$ to $10^{-5}$ | 0.05 to 3.0 | $10^{-7}$ to $10^{-5}$ |
| Polychlorinated biphenyls | 0.02 | $10^{-8}$ to $10^{-5}$ | 0.2 | $10^{-9}$ to $10^{-6}$ |
| Arsenic | 0.2 | $10^{-7}$ to $10^{-4}$ | 0.1 | $10^{-8}$ to $10^{-7}$ |
| Beryllium | 0.02 | $10^{-9}$ to $10^{-6}$ | 0.001 | $10^{-11}$ to $10^{-8}$ |
| Cadmium | 0.2 | $10^{-6}$ to $10^{-4}$ | 0.2 | $10^{-7}$ to $10^{-6}$ |
| Chromium$^{+6}$ | 0.2 | $10^{-7}$ to $10^{-4}$ | 0.1 | $10^{-7}$ to $10^{-6}$ |
| Rounded Total:[c] | 2 to 40 | $10^{-6}$ to $10^{-3}$ | 2 to 20 | $10^{-6}$ to $10^{-4}$ |

[a] The ranges in annual cancer incidence reflect the assumptions made regarding the potential carcinogenicity of classes of organic compounds.

[b] The ranges in maximum individual lifetime cancer risk reflect differences in emissions and the evaluation of emissions from MWC technologies within the existing and proposed categories.

[c] Rounded to one significant figure. Totals do not add due to rounding.

Second, a basic inconsistency exists between emission factors data and toxicity data, both of which are needed to estimate risk. Emissions data are available for mixtures or classes of organic compounds. However, toxicity data have been developed with respect to human exposure for individual organic compounds. Furthermore, toxicity data are not available for all compounds within a class. Nevertheless, scientists generally agree that structurally related compounds may exhibit similar toxic effects. Therefore, some assumptions are necessary to relate the emissions data to the risk measures and to account for the potential toxicity of various compounds in a mixture. In the case of CDD/CDF, a method involving toxic equivalency factors (TEF) was used to convert emissions of a mixture of CDD and CDF congeners to equivalent quantities of a single compound, 2,3,7,8-TCDD. The method for conversion, using weighting factors based on relative toxicities, was adopted by EPA as an interim procedure (52 FR 11749). It is described more fully in "Interim Procedures for Estimating Risks Associated with Exposure to Mixtures of Chlorinated Dibenzo-p-dioxins and Dibenzofurans (CDD and CDF)."[30]

To apply the TEF to CDD/CDF emissions, another discrepancy between emissions data and toxicity data remained to be overcome. TEF are isomer specific, but most emissions data are in terms of homologs. Emission tests on a few facilities have reported data on the emission levels of specific isomers. When TEF calculations based on isomer-specific data are compared to calculations based on homologs for those facilities, the calculations based on homologs are higher by a factor of 3 to 7. These limited data suggest that risk estimates based only on homolog-specific data may overstate the actual risk by a factor of 3 to 7. Although it is unclear whether this same pattern would hold for those facilities for which only homolog-specific data are available, the ranges shown for CDD/CDF have incorporated these factors of 3 to 7.

Additional inconsistencies between emissions data and toxicity data exist for other organics. For the classes of polycyclic aromatic hydrocarbons (PAH), chlorobenzenes, and chlorophenols unit risk factors have been established only for specific compounds within each classes: benzo(a)pyrene (a specific PAH), hexachlorobenzene, and trichlorophenol. However, emission data are available only for the class as a whole. Therefore, ranges were formed based on assumptions of the relative carcinogenicity of each class compared to the carcinogenicity of the individual compounds. Using chlorobenzenes as an example, the high risk estimate represents the assumption that all chlorobenzenes have cancer potencies equal to that of hexachlorobenzene, which is 43 percent of the mixture. The low estimate is based on the assumption that only hexachlorobenzene (of the chlorobenzenes) is associated with any risk of cancer.

The range of risk estimates from direct inhalation of formaldehyde is shown to reflect the uncertainty surrounding which tumors caused in laboratory animals by exposure to formaldehyde are indicative of formaldehyde's potential for causing cancer in humans. The low estimate is based on the assumption that only some of the tumors in animals are indicative of formaldehyde's potential for causing cancer in humans, and the high estimate is based on the assumption that all of the tumors are indicative of formaldehyde's potential for causing cancer in humans.

Still another area of uncertainty has not been incorporated in the risk ranges shown. A significant portion (80 percent or more) of the organic stack gases emitted from MWC have not been identified and quantified. Although some portion of the mixture may be carcinogenic, the carcinogenic fraction, its composition, and its potency remain unknown. If the unspeciated organics had a carcinogenic potency equivalent to the average potency of those compounds evaluated, even excluding CDD/CDF, the contribution to the annual incidence estimates could be appreciable. However, there is no information to quantify this potential source of risk.

5.1.2.2 Cancer Risk. Looking at the direct inhalation cancer risk summary shown in Tables 5-4 and 5-5, it is apparent that most of the cancer risk is attributable to organics. Table 5-6 shows further that virtually all of the total risk from existing facilities, and most of the risk from projected facilities is attributable to CDD/CDF emissions. Thus, CDD/CDF dominate the estimated total cancer risk due to direct inhalation of pollutants from municipal waste combustors.

Several potentially carcinogenic metals (arsenic, beryllium, cadmium, chromium) are emitted from municipal waste combustors in trace quantities.

Under reasonable worst case assumptions, the nationwide inhalation cancer risk associated with these emissions is estimated to be 0.5 cases per year (annual incidence) for existing sources and 0.4 annual incidence from the projected population of municipal waste combustors. Maximum individual lifetime cancer risk for the trace metals ranges from $10^{-4}$ to $10^{-7}$ for existing facilities and $10^{-6}$ to $10^{-11}$ for the projected population of combustors.

With the exception of CDD and CDF the organic carcinogens studied (chlorobenzenes, chlorophenols, formaldehyde, PAH, PCB) are estimated to pose cancer risks similar to the trace metals: 0.05-0.7 annual incidence and $10^{-5}$ to $10^{-9}$ maximum individual risk from existing sources and 0.2 to 3.0 annual incidence and $10^{-5}$ to $10^{-9}$ maximum individual risk from the projected facilities.

As is evident from Table 4, most of the estimated cancer risk is attributable to the class of CDD/CDF, measured as the equivalent to 2,3,7,8-TCDD[30]. There remain basic questions concerning the mechanism of carcinogenesis for dioxins and related compounds. The models used to estimate the plausible, upper bound carcinogenic potency of compounds such as dioxin, implicitly assume that the substance acts directly to initiate cancer. If, however, dioxin acts as a promoting agent, as some scientists believe, to amplify the carcinogenic response of other direct acting carcinogens, the present model may not be appropriate. A change of this nature in the assumption on which the cancer potency estimate is based could lead to a reduction in this estimate.

The inhalation risk estimates indicate that mass burn municipal waste combustors, and especially mass burn combustors that do not incorporate heat recovery, dominate the cancer risk from existing facilities, but RDF units contribute more than half of the higher predicted cancer incidence from projected sources.

As noted above, however, CDD/CDF risks dominate those attributable to other pollutants. The conclusions about the categories of sources contributing the most to risk, therefore, reflect assumptions about CDD/CDF emission factors for these categories of sources. CDD/CDF emission estimates from mass-burn facilities without heat recovery were based on tests from only one facility, the Philadelphia NW facility. It is impossible to determine whether emissions for this facility are representative of those from other such facilities. Facilities without heat recovery, are generally older than facilities with heat recovery, so there may be a real basis for the difference in the estimated emissions.

Similarly, the incidence estimates for existing mass-burn facilities is influenced by the emission levels found at the Hampton, VA facility, which are much higher than those found at other mass-burn facilities with heat recovery. Without further tests, one cannot determine the extent to which other facilities may have emissions as high as Hampton's. As noted above, the emissions from Hampton were excluded in calculating the average emission factor for planned facilities because the known operational problems at Hampton make it non-representative of planned facilities.

Finally, the risk attributable to planned RDF facilities is influenced by the inclusion of emission data from the SWARU facility (Hamilton, Ontario). SWARU's emissions are significantly higher than those of other RDF facilities, and SWARU had known operational problems at the time the tests were performed (which modifications have recently attempted to correct). There are insufficient emission data for RDF facilities, however, to determine whether these known problems with SWARU make its emission data unsuitable for use in estimating emissions from new RDF facilities. To reflect the knowledge of the problems encountered at SWARU, the emission factor for SWARU used in estimating emissions from new facilities was adjusted based on engineering judgment, to reflect the expected improvements through recent modifications.

5.1.2.3 Non-carcinogenic Effects. The EPA also evaluated the potential adverse, but non-carcinogenic, health effects associated with inhalation of lead and mercury emissions from municipal waste combustors. Comparisons were made between the predicted maximum modeled ambient air concentrations and the existing ambient air quality standard for lead. Comparisons were also made with a guideline for long-term ambient levels of mercury developed in setting the national emission standards for mercury (Review of National Emission Standards for Mercury, OAQPS, EPA-450/3-84-014b). The modeling results predicted no long-term concentrations above the ambient lead standard of 1.5 ug/$m^3$. Similarly, modeling predicted no long-term concentrations of mercury in excess of the guideline of 1 ug/$m^3$ under baseline conditions.

### 5.1.3 Indirect Exposure

The indirect exposure analysis was designed to test the hypothesis of whether indirect exposure routes could contribute significantly to the total exposure to municipal waste combustion emissions. The analysis evaluated both cancer and non-cancer risk. Cancer risks are estimated from the combination of exposure and carcinogenic potency factors. For non-carcinogens, exposured are compared to the threshold levels corresponding to "Risk Reference Doses" (RfDs). RfDs are based on thresholds for effects and have uncertainty factors included. The indirect exposure analysis complements the traditional direct exposure analysis by adding consideration of ingestion and dermal contact of deposited air emissions.

Several important notes should be made about the indirect exposure analysis. First, the methodology for modeling indirect exposure to pollutants emitted to the atmosphere has been reviewed by the Science Advisory Board. At this time, however, the Board's comments on the methodology have not been fully incorporated. Furthermore, chemical fate parameter data selected for use in the model were found in the published literature, but they have not been peer reviewed for this use. Because of the preliminary nature of the methodology and assumptions, the EPA feels that the reslts cannot be interpretated quantitatively at this time.

Perhaps most critically, because the objective of the analysis was to determine whether indirect exposures could contribute significantly to the total exposure due to municipal waste combustors, the analysis used conservative, potentially worst-case, assumptions about the individuals to be studied. It was impossible to model every possible combination of variables in estimating exposure due to indirect routes, so the analysis sought that set of parameters that defined the worst, but still plausible exposure case. The analysis looked at a hypothetical farm family that obtained most of their food supply from the area of maximum deposition of pollutants emitted from the stacks of municipal waste combustors, and whose children ingested 0.5 grams of dirt per day. This family was assumed to live just outside the estimated boundary (200 meters, or about one-tenth of a mile) of the modeled combustion facility. The preliminary conclusions must be interpreted in light of this worst-case scenario. The general population exposure would be expected to be less, probably significantly less.

Subject to the above assumptions and uncertainties, the preliminary analysis indicates that indirect exposure may be comparable to direct inhalation for some environmentally persistent organic carcinogens. Indirect exposures to lead and mercury also appear to warrant further analysis. As noted above, these conclusions may simply be reflective of the conservatism of the exposure scenario.

The preliminary analysis also served to indicate that indirect exposures to some pollutants were not of significant concern. The analysis found that indirect exposure to nickel, chromium (+6), beryllium, and formaldehyde would not approach reference levels under the scenarios and time frames modeled.

Analysis of the indirect exposure routes and further development of the data and methodology are continuing. This additional work will be necessary before the methodology can be used with confidence to evaluate risks from indirect exposure.

## 5.2 ENVIRONMENTAL EFFECTS

Among the pollutants found in stack gases from municipal waste combustors are acid gases, the major acid specie of concern being hydrochloric acid, HCl. Short-term and long-term modeled concentrations of HCl surrounding existing and projected sources are shown in Table 5-7. Emissions factors used to estimate HCl emissions from municipal waste combustors were calculated from the data contained in "Municipal Waste Combustion Study: Emission Data Base for Municipal Waste Combustors."[16] The average of emissions values reported were used for annual average predictions. To estimate long term ambient HCl concentrations around municipal waste combustors, the Human Exposure Model was run for all existing units and for the model units used to represent the planned population. Maximum emission values were used for the short-term modeling. Since the emissions data reported are averages over several hours and several test runs, the maximum value is a conservative choice for a short-term emission factor. The resulting ranges of maximum ambient concentrations are shown in Table 5-7.

The estimated ambient concentrations were then compared to a level associated with corrosion of metals, 3.0 ug/m$^3$,[34] and to an 8-hour threshold

## TABLE 5-7. PROJECTED AMBIENT HCl CONCENTRATIONS CONTRIBUTED BY MUNICIPAL WASTE COMBUSTORS

| SOURCES | CONTROL LEVEL | TOTAL ANNUAL EMISSIONS (Mg) | RANGE OF PREDICTED ANNUAL AVERAGE MAXIMUM CONC. (ug/m$^3$) | RANGE OF PREDICTED 1-HOUR MAXIMUM CONC. (ug/m$^3$) |
|---|---|---|---|---|
| EXISTING SOURCES | Baseline | 44,900 | .1 - 68 | 64 - 2,500 |
| | Controlled | 4,490 | .01 - 7 | 6 - 250 |
| PROJECTED SOURCES | Baseline | 194,400 | .7 - 88 | 110 - 170 |
| | Controlled | 19,400 | .07 - 9 | 11 - 17 |

limit value (TLV) for workers, 7000 $ug/m^3$.[35] The comparisons showed that short-term (1-hour) maximum concentrations do not exceed the TLV, but the majority of the existing municipal waste combustors, under the baseline scenario, would be expected to exceed the materials damage level. The modeling results for the projected facilities under the baseline scenario showed that short-term concentrations may exceed the 3.0 $ug/m^3$ level for the larger mass burn and RDF units and for all sizes of modular units, depending on location and meteorological data.

## 5.3 POSSIBLE REDUCTIONS IN IMPACTS

Reductions in predicted carcinogenic health risks and in concentrations of hydrochloric acid achievable through uniform application of dry scrubbers combined with particulate control devices is summarized in Table 5-8. As the table shows, maximum individual lifetime risk is predicted to be reduced by an order of magnitude, and annual incidence is predicted to be reduced substantially. Reductions of approximately 90 percent can also be seen in predicted hydrochloric acid concentrations.

Finally, health risk through indirect exposure routes would also be expected to be reduced; although, the extent of the potential reduction cannot be reliably estimated at this time.

As noted in Chapter 4, additional reductions in organic emissions may be achievable through combustion optimization. At this time there is insufficient information to determine the expected reduction in emissions and health risk achievable through this approach.

## 5.4 COSTS

The capital and annualized operating costs associated with controlling municipal waste combustor emissions have been estimated as described in the volume titled "Municipal Waste Combustion Study: Costs of Flue Gas Cleaning Technologies."[31] Tabular summaries of capital costs and annualized operating costs for new and existing units are included in this volume in Appendix E.

## TABLE 5-8. POSSIBLE REDUCTIONS OF HEALTH RISK AND HCl CONCENTRATIONS FROM DIRECT EMISSION PATHWAYS

| | Existing Sources | | | Projected Sources | | |
|---|---|---|---|---|---|---|
| | Mass Burn | RDF | Modular | Mass Burn | RDF | Modular |
| Baseline Estimated Cancer Incidence[a] | 1-34 | 0.3 - 2.7 | 0.01 - 0.02 | 0.6 - 7 | 1 - 14 | 0.05 - 0.9 |
| Reduction Achievable Under Controlled Scenario[a] | 0.8 - 32 | 0.3 - 2.5 | 0.01 - 0.02 | 0.4 - 6 | 0.9 - 13 | 0.04 - 0.8 |
| Baseline Estimated Maximum Individual Lifetime Risk | $10^{-4} - 10^{-3}$ | $10^{-5} - 10^{-3}$ | $10^{-6} - 10^{-4}$ | $10^{-6} - 10^{-5}$ | $10^{-5} - 10^{-4}$ | $10^{-6} - 10^{-5}$ |
| Reduction Achievable Under Controlled Scenario (orders of magnitude) | 1 | 1 | 1 | 1 | 1 | 1 |
| Baseline Estimated Maximum Long-Term HCl Concentration (ug/m$^3$) | | 0.1 - 68 | | | 0.7 - 88 | |
| Reductions Achievable Under Controlled Scenario | | 0.09 - 61 | | | 0.6 - 79 | |

[a] Rounded to precision necessary to illustrate potential reduction in annual incidence.

A model plant approach was used in the sizing and costing of the emission control systems. Due to differences in the waste feed characteristics, combustion parameters, and emissions, separate cost estimates were required for mass burning, modular, and refuse-derived fuel (RDF) combustors. Control equipment systems for which costs were evaluated included ESPs, spray dryer/ESPs, and spray dryer/fabric filters.

Capital and annualized operating costs were developed in August 1986 dollars using the cost information received from a number of air pollution control equipment manufacturers for various flue gas flow rates and design capacities. Capital cost estimates were developed for 25 percent excess combustor capacity and were increased by an additional 20 percent to account for contingencies. They include the cost of the control system and auxiliary equipment (i.e., ductwork and I.D. fan). In addition, a credit was included in the calculations of the capital costs for those control systems which include spray dryers to account for the reduction in capital cost for a stack that does not require acid-resistant lining.

The increase in capital cost for control equipment at new facilities with the addition of spray drying ranges from 50 to 500 percent. The lower end of the range is for the mass burn and RDF model facilities while the higher value is for modular facilities. Spray dryer/fabric filter systems require 0.5 to 5.5 percent less capital than spray dryer/ESP systems for 1,000 ton per day and larger mass burn and RDF model facility sizes at the 0.03 gr/dscf particulate matter emission level; the savings become 5 to 8 percent at the 0.01 gr/dscf level. For the modular model facilities, spray dryer/fabric filter systems require an additional 30 percent of capital as compared to a similarly designed spray dryer/ESP system.

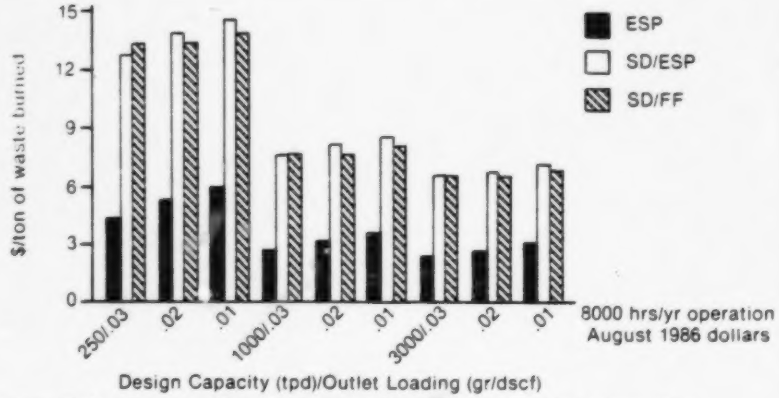
Annualized operating cost estimates for control equipment at new facilities incorporate assumptions of 8,000 operating hours per year, 20 years of equipment life for ESPs, and 15 years of equipment life for spray dryers combined with fabric filters and for spray dryers combined with ESPs. Maintenance costs were assumed to be 2 percent of the total capital cost, the waste disposal cost was assumed to be $15/ton, and taxes and insurance were estimated to be 4 percent of the total capital cost.

Indirect operating costs (i.e., primarily repayment of capital) are more significant than direct operating costs in each of the annualized operating cost estimates for new facilities. Indirect costs represent from 60 to 80 percent of the total annualized cost of operating the emission control systems for new mass burn and modular facilities. The indirect operating costs are slightly lower (55 to 70 percent of the total annualized operating cost) for the RDF facilities.

The waste disposal cost is the major component of the direct operating costs. Waste disposal costs represent from 25 to 40 percent of the total direct cost of particulate matter emission control systems (ESPs) for mass burn facilities. Waste disposal cost for particulate matter control only for RDF facilities is 50 to 60 percent of the direct operating costs. The waste disposal cost associated with spray dryer/ESP and spray dryer/fabric filter systems are 15 to 30 percent for mass burn facilities and approximately 40 percent for RDF facilities. The waste disposal cost is insignificant for modular facilities due to the small quantities of particulate matter generated. Obviously, these control costs depend to a large extent on landfill costs.

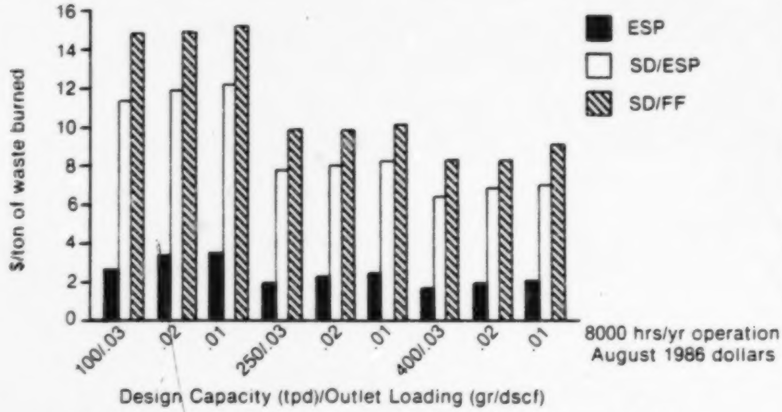
Figures 5-1 through 5-3 present the annualized operating cost estimates for the emission control systems for new model plants in terms of dollars per ton of refuse burned. All figures indicate that the relative costs of operating the emission control systems decrease as the facility sizes increase. Also, as the particulate matter emission control levels become more stringent, the annualized operating costs increase. The additional cost of spray drying compared to PM control alone is $4 to $9 per ton of waste burned for mass burn facilities. For the RDF model plants, the addition of spray dryers accounts for an additional $4 to $5 per ton. The corresponding cost for the model modular facilities is $5 to $12 per ton of waste burned.

The spray dryer/ESP system is generally slightly more costly to operate than the spray dryer/fabric filter system, based on the information presented in Figures 5-1, 5-2, and 5-3. The exceptions are mass burn model plants at the 0.03 gr/dscf outlet particulate matter loading and the modular model plants.



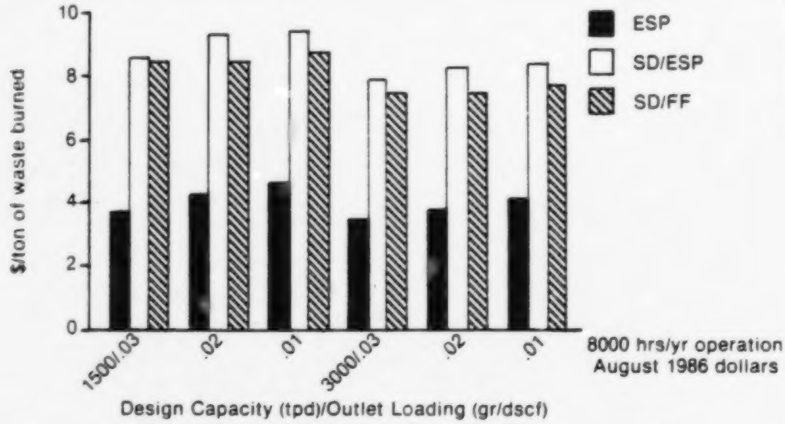
8000 hrs/yr operation
August 1986 dollars

Figure 5-1. Annualized Operating Cost Estimates for Model Mass Burning Facilities



8000 hrs/yr operation
August 1986 dollars

Figure 5-2. Annualized Operating Cost Estimates for Model Modular Combustor Facilities



8000 hrs/yr operation
August 1986 dollars

Figure 5-3. Annualized Operating Cost Estimates for Model Refuse-Derived Fuel Burning Facilities

6870341R

Capital cost estimates for control equipment at existing municipal waste combustion facilities must take into account the additional expense of retrofitting additional control equipment into an existing control system. For example, the capital cost for a spray dryer/ESP system at an existing massburn or RDF facility with a highly efficient ESP currently in place would be estimated on the basis of the spray dryer cost times a retrofit factor of 1.4. Similarly, the retrofit factor for estimating the cost of a spray dryer/fabric filter at an existing massburn or RDF facility with a wet scrubber or a less efficient ESP in place would be 1.8. Finally, the capital cost of retrofit combustion improvements at an existing facility is estimated to be $6.5 million per 1000 tons per day capacity. Operating costs or savings can not be determined on a general basis. These retrofit factors are based on extremely limited data and are highly uncertain, especially in view of the site-specific nature of retrofits.

The emission control systems costed for existing municipal waste combustion facilities were designed to provide particulate matter control only or both acid gas and particulate matter control. For existing mass burn and RDF facilities the control systems evaluated included a spray dryer system retrofit to facilities with a highly efficient ESP in place and a spray dryer/fabric filter system retrofit to facilities with a wet scrubber or less efficient ESP currently in place. The majority of existing modular facilities are uncontrolled. Therefore, ESPs and spray dryer combined with ESPs were evaluated for modular facilities.

The cost for modification of one existing combustor and retrofit of a new particulate matter control device at Quebec City was slightly less than $1.5 million. This cost included a computerized process control system designed to operate four combustors at the facility.[36]

## 5.5 COST/RISK ANALYSIS

The previous discussion has presented the health risk estimates expected from municipal waste combustors under two different control scenarios and reductions in risk that might be achieved through uniform application of alkaline scrubbers combined with particulate matter emissions control. This was followed by an analysis of monetary costs of the two levels of control: 1) ESPs and 2) spray dryers combined with ESP or fabric filter particulate controls.

This section seeks to weigh costs and risk reductions and other benefits achievable. Table 5-9 is a direct comparison of the incremental cost of the stringent control case with cancer risk due to direct inhalation that could be reduced through application of stringent control measures, both calculated for the entire U.S.

Direct inhalation cancer risk reduction is one of several benefits that would accrue through the uniform addition of alkaline scrubbers to the baseline particulate matter control technology. Emissions to the air of HCl, particulate matter, and volatile organic compounds (VOC) would also be reduced. Furthermore, exposure through indirect routes would also be reduced, including exposure to non-carcinogens. Although these additional benefits are not accounted for quantitatively in the cost/risk comparison quotients presented in Table 5-9, they are, nonetheless, real benefits which must be considered.

## TABLE 5-9. INCREMENTAL COST/RISK COMPARISON

| | EXISTING SOURCES | | | PROJECTED SOURCES | | | |
|---|---|---|---|---|---|---|---|
| | Mass Burn | RDF | Modular | Mass Burn | RDF | Modular | TOTAL |
| DIRECT INHALATION EXPOSURE:[a] | | | | | | | |
| Baseline Cancer Incidence (annual) | 1 - 34 | 0.3 - 2.7 | 0.01 - .02 | 0 .6 - 7 | 1 - 14 | 0.05 - 0.9 | 1.7 - 31 |
| Incidence Reduction Obtainable Through Controlled Scenario[b] | 0.8 - 32 | 0.3 - 2.5 | 0.01 - .02 | 0.4 - 6 | 0.9 - 13 | 0.04 - 0.9 | 1.3 - 29 |
| Maximum Individual Lifetime Risk (baseline scenario) | $10^{-4}$ - $10^{-3}$ | $10^{-5}$ - $10^{-3}$ | $10^{-6}$ - $10^{-4}$ | $10^{-6}$ - $10^{-5}$ | $10^{-5}$ - $10^{-4}$ | $10^{-6}$ - $10^{-5}$ | $10^{-6}$ - $10^{-4}$ |
| INCREMENTAL COST OF CONTROL:[c] (million $) | 85 - 127 | 29 - 45 | 4.6 - 23 | 201 | 62 | 17 | 280 |
| COST EFFECTIVENESS[b] (million $/cancer case avoided) | 2.7 - 160 | 11 - 150 | 230-2300 | 34 - 503 | 4.8 - 69 | 19 - 425 | 9.7 -215 |

---

[a] Rounded to precision necessary to facilitate cost/risk comparison.

[b] Does not consider benefits resulting from reduced emissions of mercury, HCl, particulate matter, or volatile organic compounds; nor reduction in potential indirect exposure.

[c] Difference between annualized cost of 2 control scenarios.

# 6. SAMPLING, ANALYSIS AND MONITORING*

One of the most rapidly developing areas within the overall subject of municipal waste combustion is sampling, analysis, and monitoring of municipal waste combustor emissions and waste streams. In the analytical chemistry field alone, the state of the art has moved rapidly from semi-quantitative for selected isomers of CDD and CDF in the late 1970s to quantitative determination of all CDD and CDF isomers today. In this section a brief summary of sampling, analytical and monitoring methods is offered. More detail may be found in "Municipal Waste Combustion Study: Sampling and Analysis of Municipal Waste Combustors."[32]

## 6.1 SAMPLING

Stack testing at municipal waste combustors has been carried out for a variety of air pollutants in several categories, including:

- Criteria pollutants (particulate matter, CO, $SO_x$, $NO_x$, lead)
- Acid gases (HCl, HF)
- Metals (Cr, Cd, As, Hg, Ni, Be, etc.)
- Organics (CDD, CDF, and others)

Characterization and leachate testing has also been carried out for ash residues.

For both flue gas and bottom ash sampling a difficulty arises in obtaining representative samples. For example, flue gas sampling may be complicated by uneven flow conditions and by high particulate matter and acid gas loadings that clog or corrode conventional sampling equipment. Other problems may be encountered in sampling bottom ash which may include bulky items, such as metal containers.

---

*Information presented in this section is summarized from Reference 32, Municipal Waste Combustion Study: Sampling and Analysis of Municipal Waste Combustors.

Table 6-1 lists EPA-approved stack sampling methods for various pollutants. Most of these methods have been subjected to extensive development and validation procedures. Moreover, a number of these methods have been employed in recent municipal waste combustion sampling and analysis programs.

The EPA Method 5 type train has been the principal method for stack sampling of criteria pollutants, acid gases, metals, and semi-volatile organics, including CDD, CDF, and PAH, chlorobenzenes and chlorophenols. The Modified Method 5 train incorporates a condenser section and a module filled with solid sorbent between the exit of the filter and the entrance to the first impinger. It should be noted that testing is underway to verify recoveries of organic compounds using this modified train. New developments are occurring rapidly and should be monitored closely.

The number of sampling trains and sample runs required for stack sampling of a municipal waste combustor depends on the list of pollutants specified for quantification and the accuracy and precision with which concentrations must be measured. Quantitative results for an extensive list of pollutants may require multiple determinations of the same chemical specie and, generally speaking, no more than 2 to 3 species can be determined from one train. The situation is further complicated by physical limitations due to restricted space in the stack sampling area and the number of sampling ports available in one plane. Even if ports are available, the logistics of running more than two trains can be complicated. These physical limitations limit the number of trains that can be run simultaneously. For example, for a recent EPA test of a municipal waste combustor, stack gases were to be sampled by manual methods in three separate runs for CDD/CDF, HCl, Pb, Cd, Cr, Ni, and particulate matter. $SO_2$ and $O_2$ were measured with continuous emissions monitors. Sampling for this list of pollutants required four separate trains. For statistically significant data at least triplicate measurements per species were required, resulting in a total of 12 separate runs. The site specific considerations of a circular duct with two sampling ports and an actual sampling time of 4 to 6 hours for each run, based on expected concentrations in the stack, restricted the test program to 2 runs a day for a total of six sampling days.[33]

## TABLE 6-1. STACK (FLUE GAS) SAMPLING METHODS

| Pollutant | Principle | Comment | Reference |
|---|---|---|---|
| Criteria and Conventional Parameters | | | |
| Particulate | Isokinetic collection of a 1 hr. sample on glass fiber filter at $120 \pm 14^{\circ}$C. Train includes: T-controlled probe, optional cyclones, heated filter, impingers, flow control and gas volume metering system. | Designed to meet 0.08 gr/SCF standard. Probably valid down to 0.01 gr/SCF. | EPA Meth. 5 |
| | Visual determination of opacity | | EPA Meth. 9 |
| | Instrumental measurement of opacity (optical density) | Not reliable for quantification at 0.03 gr/SCR or below. | - |
| Sulfur Oxides | Collection in isopropanol ($SO_3$) and hydrogen peroxide ($SO_2$) impingers of M5-type train. | Low ppm to percent | EPA Meth. 6,8 |
| Carbon Monoxide | Integrated gas bag or direct interface via air-cooled condenser. | Water vapor, carbon dioxide are interferences; need silica gel, ascarite traps to remove.<br>20-1000 ppm | EPA Meth. 10 |
| Nitrogen Oxides | Collection in evacuated flask containing sulfuric acid and hydrogen peroxide. | Grab sample (not time-integrated)<br>ppm levels<br>Does not measure NO | EPA Meth. 7,7A |

TABLE 6-1. STACK (FLUE GAS) SAMPLING METHODS (Continued)

| Pollutant | Principle | Comment | Reference |
|---|---|---|---|
| Hydrochloric Acid | Collection in aqueous NaOH impingers in M5-type train. | ppm to percent range. | (18) |
| Hydrogen Fluoride | Collection on paper or membrane (not glass fiber) filter and aqueous impingers in M5-type train. | Low ppm range. | EPA Meth. 13B |
| Trace Metals | | | |
| General | M5 or SASS train, glass fiber filter and nitric acid or ammonium persulfate impingers | ppb to ppm levels if is _ 0.75 $M^3$ of stack gas | (18) |
| Lead | Collection on glass fiber filter and nitric acid impingers in M5-type train. | | EPA Meth. 12 |
| Mercury | Collection in iodine monochloride or acidic permanganate impingers in M5-type train. | Probe must be glass- or quartz-lined.<br>ppm levels. Other reagents also possible. | EPA Meth. 101 |
| Arsenic | Collection on glass fiber filter and aqueous impingers in M5-type train. | | EPA Meth. 108 |
| Beryllium | Collection on millipore AA filter and aqueous impingers in M5-type train. | Probe must be glass or quartz-lined. | EPA Meth. 104 |

TABLE 6-1. STACK (FLUE GAS) SAMPLING METHODS (Continued)

| Pollutant | Principle | Comment | Reference |
|---|---|---|---|
| Trace Organics | | | |
| Specific Volatile organics | Collection on Tenax-GC and charcoal at 1 LPM for 20 minutes. | ppb-ppm levels;multiple species | VOST |
| Semi-volatile organics, including dioxins, furans | M5 train modified to include XAD-2 trap for organic collection between filter and impingers. | ppb-ppm levels; multiple species | MM5 |
| | 5-fold scale up of MM5 system. | sub-ppb levels for dioxins/furans if dedicated sample | SASS |
| Vinyl chloride | Integrated gas bag | 0.1-50 ppm | EPA Meth. 106 |
| Formaldehyde | Collection on DNPH-coated sorbent or in aqueous DNPH impingers. | ppm levels | - |
| Gaseous Hydrocarbons, total | Integrated bag sample or direct interface | ppm levels | EPA Meth. 18 |
| Gaseous Hydrocarbons, total | Evacuated stainless steel or aluminum tank behind chilled condensate trap. | | EPA Meth. 25 |

## 6.2 SAMPLE PREPARATION

Stack samples taken from municipal waste combustors must be converted into a matrix which is compatible with the analytical methods needed. Table 6-2 summarizes sample preparation procedures commonly used for municipal waste combustor stack samples.

In some cases (e.g., analysis of chloride in caustic impinger solutions) the required sample preparation may be minimal. In other case (e.g. analysis of CDDs/CDFs in a Modified Method 5 stack gas sample) preparation procedures may be complex, requiring multiple extraction, concentration, and clean-up steps. (See Table 6-2.)

The use of surrogate or standard addition methods is recommended as a check on losses in sample preparation procedures. Additions should be made prior to sample preparation.

## 6.3 ANALYSIS

Analytical methods are available for most chemical species likely to be selected for quantification in emissions and effluents from municipal waste combustors. Table 6-3 shows analytical methods for organics and metals that may be specified in testing requirements.

## 6.4 MONITORING

Continuous monitoring at municipal waste combustors may be carried out for:

- temperature
- opacity
- $CO$, $CO_2$, $NO_x$, $SO_2$ concentration
- HCl concentration
- total hydrocarbon concentration

## TABLE 6-2. SUMMARY OF SAMPLE PREPARATION METHODS

| MSW Combustor Stream | Sample Type | For Analysis of | Preparation Procedure |
|---|---|---|---|
| Stack Gas | M5, MM5 or SASS | | |
| | - probe wash<br>- filter | Particulate | Dissicate to constant weight |
| | -probe wash<br>- filter<br>- impinger solutions | Metals | Standard addition to split samples. Digest in acidic oxidizing medium. |
| | - probe wash<br>- filter<br>- sorbent module | Semivolatile organics | Add surrogate. Soxhlet extract with $CH_2Cl_2$. Concentrate. Clean-up as necessary. |
| | - condensate | Semivolatile | Add surrogate Liquid-liquid extract at pH 2 and pH 11 with $CH_2Cl_2$. Concentrate. Clean-up as necessary. |
| | VOST<br>- sorbent cartridges | Volatile organics | Spike with internal standard. Thermally desorb onto analytical trap. Desorb this trap into GC/MS. |
| | - condensate | Volatile organics | Spike with internal standard. Purge onto analytical trap. Desorb into GC/MS. |
| Flue Gas | M5, MM5, SASS | (same as for stack gas) | |
| | VOST | | |
| Bottom Ash and Fly Ash | Composite Grab | Metals | Standard addition to split samples. Digest in acidic medium in Parr bomb. |

## TABLE 6-2. SUMMARY OF SAMPLE PREPARATION METHODS (Continued)

| MSW Combustor Stream | Sample Type | For Analysis of | Preparation Procedure |
|---|---|---|---|
| | | Semi-volatile organics | Add surrogate. Soxhlet extract with $CH_2Cl_2$. Concentrate. Clean-up as necessary. |
| Liquid Effluents | Composite Grab | Metals | Standard addition to split samples. Digest in acidic, oxidizing medium. |
| | | Volatile Organics | Spike with internal standard. Purge into analytical trap. Desorb into GC/MS. |
| | | Semivolatile Organics | Add surrogate. Liquid extract at pH 2 and pH 11 with $CH_2Cl_2$. Concentrate. Clean-up as necessary. |
| Waste Feed | Composite Grab | | Grind or mill to reduce particle size. Take subsamples. |
| | | Metals | |
| | | Semivolatile Organics | Same as for ash samples. |
| | | Volatile[a] Organics | Spike with internal standard. Dilute in reagent water or polyethylene glycol in purge cell. Purge, trap and desorb into GC/MS. |

---

[a] Reference: Miller, N.C., R.W. James and W.R. Dickson, "Evaluated Methodology for the Analysis of Residual Waste, "Report prepared under EPA Contract No. 68-02-1685 (December 1980).

TABLE 6-3. ANALYSIS METHODS FOR TRACE ORGANICS AND TRACE METALS, APPLICABLE TO MUNICIPAL WASTE COMBUSTOR SAMPLES

| Species | Method |
|---|---|
| Volatile Organics | Pack column GC/MS; full mass range scanning 20-260 amu. |
| Semivolatile Organics | Capillary column GC/MS; full mass range scanning 40-500 amu. |
| Dioxins/Furans | Capillary column GC/MS; selected ion monitoring. |
| Metals | Flame (high levels) or furnace (low levels) AAS.<br>Inductively coupled plasma spectroscopy (not for mercury, lead, arsenic) |

Possible continuous monitoring devices for measuring these variables and gas concentrations in municipal waste combustor stack gases are summarized in Table 6-4. Most pollutants are measured using an extractive method where the flue gas is withdrawn from the stack, transferred in a heat traced line to ground-level to an instrument trailer where the flue gas is conditioned to remove moisture and then split for analysis by individual instruments. Particulates and temperature are two parameters which are usually measured in-situ.

Continuous temperature measurements in combustor flue or stack gases are generally accomplished by using thermocouples. The thermocouples must be shielded from radiation and protected against mechanical damage and corrosion by shielding inside a ceramic or metal protection tube or in a thermowell.

Continuous monitoring of particulate material is generally accomplished using an in situ opacity meter. Typically, these devices measure changes in optical density, OD (percent transmittance), due to scattering and/or adsorption of light by particulates that are present, but their performance is affected by particle size distribution, the particulate shape, particle composition, the system's temperature, the presence or absence of water droplets and the configuration of the stack. Also, commercially available opacity meters for stack monitoring may be uncertain by a factor of two or more at particulate loadings below 0.03 gr/scf. The lack of measurement specificity of the instrument may render opacity monitors less reliable at municipal waste combustors than at other stationary sources, since waste feed is highly variable, emission levels and compositions may vary significantly over time.

$SO_2$, $NO_x$ and HCl concentrations can be measured using instruments based on several different principles. Perhaps the most common detection principle used by continuous analyzers for stack gases is nondispersive infrared (NDIR). The principal advantages of NDIR based instrumentation is the fact that it is comparatively low in cost and that the technology is applicable to a wide variety of pollutant species. Also, instruments are relatively rugged and commercially available systems have been in use in field monitoring situations for many years. Problems that are associated with this detection principal are that other chemical species will absorb similar signature wavelengths of

## TABLE 6-4. CONTINUOUS MONITORING DEVICES FOR MUNICIPAL WASTE COMBUSTORS

| | |
|---|---|
| Temperature | Thermocouple |
| Opacity | Opacity meter |
| CO concentration | Nondispersive Infrared<br>Polarographic |
| Oxygen Concentration[a] | Polarographic<br>Electrocatalytic<br>Paramagnetic |
| $SO_2$ Concentration[a] | Nondispersive Infrared<br>Nondispersive Ultraviolet<br>Polarographic |
| $NO_x$ Concentration[a] | Nondispersive Infrared (NO)<br>Nondispersive Ultraviolet ($NO_2$)<br>Polarographic (NO)<br>Chemiluminscent |
| HCl Concentration[a] | Nondispersive Infrared<br>Polarographic |
| Total Hydrocarbon Concentration[a] | Flame ionization detector<br>Infrared detection<br>Catalytic combustion detector<br>Thermal conductivity detector |

---

[a] Using an extractive method.

infrared light, and the fact that optical systems needed to produce, transmit, and receive the generated infrared light may degrade due to contact with the sample gas.

Non-dispersive ultraviolet analyzers have an important advantage over NDIR analyzers in that in the NDUV analyzers water vapor is not an interference, as water does not absorb light in the ultraviolet region of the spectrum. As is the case with most extractive monitoring techniques, however, particulates which will absorb or scatter generated light must be removed from the sample gas stream.

Numerous pollutant species of potential interest at municipal waste combustors may be measured continuously using polarographic analyzers. The polarographic analyzers offer several advantages over other analyzers, including multi-pollutant capability, fast response and simplicity of operation. Principle disadvantages of this technique are that parts of the system must be replaced or rejuvenated periodically, and the instrument must be frequently calibrated because the response deteriorates with use.

Oxygen may be measured continuously using electrocatalytic analyzers and paramagnetic oxygen analyzers. Chemiluminescence may be used for inorganic pollutants, most notably nitrous oxide and ozone.

Hydrocarbons may be monitored continuously with a flame ionization detector (FID) or an infrared detection (IRD). These detectors are relatively rugged and are quite sensitive to hydrocarbons. Response factors are generally lower for organics that incorporate functional groups such as halides, hydroxyl, carbonyl, carboxylate. The photoionization detector (PID) is applicable to many organic categories, but experience with this detector as a continuous monitor is more limited. There is some evidence that maintenance is more of an issue with PID than with FID or IR instruments.

The electron capture detector (ECD), which has high sensitivity and selectivity for halogenated organics under laboratory conditions, is not rugged enough for routine continuous monitoring in the field. Also, because these detectors contain radioactive materials, NRC permitting regulations govern their installation and use. The Hall detector, also specific for halogenated species, has been used at hazardous waste incineration sites, but with difficulty.

Catalytic combustion (hot wire) and thermal conductivity detectors are also used for continuous monitoring of organics. However, most commercially available instruments based on these principles are generally designed for gases and vapors. A few low-level instruments suitable for municipal waste combustor monitoring are available, however.

Monitoring of specific organic compounds, rather than total organics, require that chromatographic separation be accomplished prior to detection. Instrumental monitors that interface a gas chromatograph to an FID or PID are commercially available. These operate in a semi-continuous basis, since the chromatographic separation imposes a cycle time of (typically) 5-30 minutes between measurements. GC/FID or GC/PID analyzers are vulnerable to false positive interferences because the retention time is an imperfect means of compound identification.

Instruments based on more selective detection principles (e.g., GC/MS or GC/FTIR) are beyond the present state-of-the-art for stack monitoring, except in research installations. Instruments using these detectors may be sufficiently expensive to install and demanding to operate that they are not suitable for routine continuous monitoring. Most require more stringent control of temperature, humidity and power supply than is likely to be practiced at an operating municipal waste combustion plant.

Continuous monitoring requires close attention to calibration and other quality assurance measures. These topics and additional information on monitoring of stack gases at municipal waste combustors are covered in "Municipal Waste Combustion Study: Sampling and Analysis of Municipal Waste Combustion."[32]

# 7. REFERENCES

1. Ballschmiter, et. al. Automobile Exhauses Versus Municipal-Waste Incineration as Sources of the Polychloro-Dibenzodioxins (PCDD) and Furans (PCDF) found in the environment. Chemosphere Vol. 15, No. 7. pp. 901-915. 1986.

2. Ballschmiter, K. and H. Buchert. Polychloratibenzofurans (PCDF) and -Dioxins (PCDD) as Part of the General Pollution in Environmental Samples of Urban Areas. Chemosphere. Vol 15., Nos. 9-12. pp. 1923-1926. 1986.

3. Ballschmiter, K. et. al. Occurrence and Absence of Polychlorodibenzofurans and Polychlorodibenzodioxins in Fly Ash from Municipal Incinerators. Chemosphere. Vol 12, No. 4/5. pp. 584-594. 1983.

4. Barnes, Donald F. "Dioxins" Production from Combustion of Biomass and Waste. Presented at Symposium on Energy from Biomass and Wastes VII. Lake Buena Vista, Florida. January 24-18, 1983.

5. The Trace Chemistries of Fire-A Source of and Routes for the Entry of Chlorinated Dioxins into the Environment. The Chlorinated Dioxin Task Force, The Michigan Division, Dow Chemical U.S.A., 1978.

6. U.S. Environmental Protection Agency. Municipal Waste Combustion Study: Characterization of the Municipal Waste Combustion Industry. EPA/530-SW-~~87-021h~~. Prepared by Radian Corporation, June 1987.

7. Franklin Associates, LTD. Characterization of Municipal Solid Waste in the United States, 1960 to 2000. Final Report. EPA Contract No. 68-01-7037, WA 349. July 11, 1986.

8. New Jersey Department of Environmental Protection - Division of Waste Management. Progress in Waste Management - A Solution to New Jersey's Garbage Dilemma. March 1986.

9. Garbage: A 413,000 Ton-A-Day-Dilemma, Inform Reports. 5(3):1-4. May-June 1985.

10. U.S. Environmental Protection Agency. Survey of selected firms in the Commercial Hazardous Waste Management Industry: 1984 Update. Final Report. Prepared by ICF Incorporated. September 30, 1985.

11. Johnson, Charles A. and C.L. Pettit. The 1986 Tip Fee Survey Documenting Rising Prices. Waste Age. March 1987. pp. 61-64.

12. Hertzberg, Richard. New Directions in Solid Waste and Recycling. Biocycle. Volume 27, January 1986. pp. 22-26.

13. Update: Resource Recovery Activities Report. Waste Age. 16 (11):99-183. November 1985.

14. Introduction to the ORFA Process and ORFA Corporation of America. September 1986. Cherry Hill, NJ.

15. Concord Scientific Corporation. National Incinerator Testing & Evaluation Program. P.E.I. Testing Program. Prepared for Environmental Canada. July 1985.

16. U.S. Environmental Protection Agency. Municipal Waste Combustion Study: Emissions Data Base for Municipal Waste Combustors. EPA/530-SW-87-021b. Prepared by Midwest Research Institute. June 1987.

17. Seeker, W.R., W.S. Lanier, and M.P. Heep. Municipal Waste Combustion Study: Combustion Control of Organic Emissions. EPA/530-SW-87-021c. June 1987.

18. Acurex Corporation. Assessment of Flue Gas Cleaning Technology for Municipal Waste Combustion. Final Report. EPA Contract No. 68-02-3993, Work Assignment 11031. Prepared for Environmental Protection Agency, Research Triangle Park, NC. September 1986.

19. Brna, Theodore G., and Charles B. Sedman. Municipal Waste Combustion Study: Flue Gas Cleaning Technology. EPA/530-SW-87-021d. U.S. Environmental Protection Agency, Research Triangle Park, NC. June 22, 1987.

20. Kramlich, J.C., M.P. Heap, W.R. Seeker, and G.S. Samuelson. Flame Mode Destruction of Hazardous Waste Compounds in 20th Symposium (International) on Combustion.

21. Finkelstein, A. et al. Presentation by Environmental Canada at Municipal Solid Waste Incineration Research and Planning Meeting. Durham, NC. December 9-11, 1986.

22. Federal Register 48:48932 (October 21, 1983). Standards of Performance for New Stationary Sources: VOC Emissions from the SOCMI Air Oxidation Unit Processes.

23. Trenholm, A., P. Gorman, and F. Jungclaus. Performance Evaluation of Full-Scale Hazardous Waste Incinerators. 3 Volumes. PB 85 1296528, PB 85 129518, PB 85 129531. U.S. Environmental Protection Agency, Cincinnati, OH. November 1984.

24. Nielsen, K.K., J.T. Moellers and S. Rasmussen. Reduction of Dioxins and Furans by Spray Dryer Absorption from Incinerator Flue Gas. Presented at Dioxin 85, Bayreuth, W. Germany. September 19, 1985.

25. Environment Canada. The National Incinerator Testing and Evaluation Program. Air Pollution Control Technology. Summary Report. Report EPS 3/UP/2. September 1986.

26. Moller, J. Thousig, K. Kragh Nielsen, and E. Jons. New Developments in Spray Dryer Absorption of Household Incinerator Flue Gas. Presented at International Recycling Congress. Berlin. October 29-31, 1986.

27. U.S. Environmental Protection Agency. Municipal Waste Combustion Study: Assessment of Health Risks Associated with Municipal Waste Combustion Emissions. EPA/530-SW-87-021g. U.S. Environmental Protection Agency, Research Triangle Park, NC. June 1987.

28. U.S. Environmental Protection Agency. User's Manual for the Human Exposure Model (HEM). EPA-450/5-86-001. Research Triangle Park, NC. June 1986.

29. U.S. Environmental Protection Agency. Industrial Source Complex (ISC) Dispersion Model User's Guide - Second Edition. EPA-450/4-86-005a. Research Triangle Park, NC. June 1986.

30. U.S. Environmental Protection Agency. Interim Procedures for Estimating Risks Associated with Exposures to Mixtures of Chlorinated Dibenzodioxins and -Dibenzofurans (CDD and CDF). EPA-625/3-87-012, March 1987.

31. Johnston, Michael. Municipal Waste Combustion Study: Costs of Flue Gas Cleaning Technologies. EPA/530-SW-87-021e. U.S. Environmental Protection Agency, Research Triangle Park, NC. June 1987.

32. U.S. Environmental Protection Agency. Municipal Waste Combustion Study: Sampling and Analysis of Municipal Waste Combustors. EPA/530-SW-87-021f. Prepared by Arthur D. Little, Inc. June 1987.

33. Jamgochian, Carol L., Winton E. Kelly, and Donna J. Holder. Revised Sampling and Analytical Plan for the Marion County Solid Waste-To-Energy Facility Boiler Outlet. Salem, Oregon. EPA Contract No. 68-02-4338. Prepared for Environmental Protection, Research Triangle Park, NC. September 1986.

34. Telecon. Kellam, Bob, Section Chief. U.S. Environmental Protection Agency, with Joanne Wiersma, Section Chief, Texas Air Control Board. June 1987.

35. American Conference of Government Industrial Hygienists. Threshold Limit Values and Biological Exposure Indices for 1986-1987. ISBN:0-936712-69-4. Cincinnati, Ohio.

36. Telecon. Johnston, Mike, EPA:OAQPS with Abe Finklestein, Environment Canada. February 24, 1987. Conversation about modifications at Quebec City.

37. U.S. Environmental Protection Agency. Municipal Waste Combustion Study: Emissions Data Base for Municipal Waste Combustors. Review Draft. EPA Contract No. 68-02-3817. Prepared by Midwest Research Institute. January 1987.

# APPENDIX A

## DOCUMENTS PREPARED BY THE EPA'S ENVIRONMENTAL CRITERIA ASSESSMENT OFFICE

# INTRODUCTION

The following documents were prepared by the Office of Health and Environmental Assessment for the Office of Air Quality Planning and Standards. These documents are of three types: Air Quality Criteria Documents, Health Assessment Documents, and Health Issue Assessments. Brief descriptions of these document types follow:

> Air Quality Criteria Documents (AQCD) are the primary source of information used by EPA decision makers in setting or revising the National Ambient Air Quality Criteria Standards. These documents are evaluations of the available scientific literature on the health and welfare effects of criteria pollutants. Criteria documents are mandated by the Clean Air Act and are revised at 5-year intervals, as directed by the Act.
>
> Health Assessment Documents (HAD) are comprehensive evaluations of health data, including carcinogenicity, mutagenicity, and other effects due to exposure to particular chemicals or compounds. These documents serve as the scientific data base for establishing relationships between ambient air concentrations and potential health risks and are used to determine the possible listing of hazardous air pollutants under Sections 111 and 112 of the Clean Air Act.
>
> Health Issue Assessments (HIA) are an initial review of the scientific literature concerning the most important health effects associated with a given chemical substance. These assessments may be published as is, or developed into a comprehensive health assessment document if evidence suggests that significant health effects may be associated with environmental exposures to a specific substance.

## ECAO DOCUMENTS

| Document Title | Document Type | EPA Number (600/)* | NTIS Number (PB-) |
|---|---|---|---|
| Acrolein | HAD | 8-86-014A | 87-139960/AS |
| Acrylonitrile | HAD | 8-82-007F | 84-149152 |
| Arsenic | HAD | 8-83-021F | 84-190891 |
| Asbestos | HAD | 8-84-003F | 86-242864 |
| Beryllium | HAD | 8-84-026B | 86-183944 |
| Butadiene, 1,3- | HAD | 8-85-004F | 86-125507/AS |
| CFC-113 | HAD | 8-82-002F | 84-118843 |
| Cadmium | HAD | 8-81-023 | 82-115163 |
| Cadmium-Updated Mutagenicity and Carcinogenicity Assessment | HAD Addendum | 8-83-025F | 85-243533 |
| Carbon Monoxide | AQCD | 8-79-022 | 81-244840 |
| Carbon Monoxide-Revised Evaluation of Health Effects | AQCD Addendum | 8-83-033F | 85-103471 |
| Carbon Tetrachloride | HAD | 8-82-001F | 85-124196 |
| Chlorinated Benzenes | HAD | 8-84-015F | 85-150332 |
| Chloroform | HAD | 8-84-004F | 86-105004 |
| Chloroprene | HIA | 8-85-011F | 86-197662 |
| Chromium | HAD | 8-83-014F | 85-115905 |
| Copper | HIA | 8-87-001F | 87-137733 |
| Coke Oven Emissions | HAD | 8-82-003F | 84-170182 |
| Dibenzofurans | HAD | 8-86-018A | 86-221256 |
| Dioxins | HAD | 8-84-014F | 86-122546 |
| Epichlorohydrin | HAD | 8-83-032F | 85-132363 |
| Ethylene Dichloride | HAD | 8-84-006F | 86-122702 |

## ECAO DOCUMENTS

| Document Title | Document Type | EPA Number (600/)* | NTIS Number (PB-) |
|---|---|---|---|
| Ethylene Oxide | HAD | 8-84-009F | 86-102597 |
| Hexachlorocyclopentadiene | HAD | 8-84-001F | 85-124915 |
| Hydrocarbons | AQCD | 8-81-022 | 82-136516 |
| Hydrogen Sulfide | HAD | 8-86-026A | 87-117420 |
| Lead (4 volumes) | AQCD | 8-83-028F | 87-142378 |
| Manganese | HAD | 8-83-013F | 84-229954 |
| Mercury | HIA | 8-84-019F | 85-123925 |
| Methyl Chloroform | HAD | 8-82-003F | 84-183565 |
| Methylene Chloride | HAD | 8-82-004F | 85-191559/AS |
| Methylene Chloride-Updated Carcinogenicity Assessment | HAD Addendum | 8-82-004FF | 86-123742 |
| Nickel | HAD | 8-83-012FF | 86-23212 |
| Nitrogen Oxides | AQCD | 8-82-026F | 83-163337 |
| Ozone (5 volumes) | AQCD | 8-84-020F | 87-142949 |
| Polycyclic Organic Matter | HAD | 9-79-008 | 82-186792 |
| Particulate Matter/ Sulfur Oxides | AQCD | 8-82-029F | 84-156777 |
| Particulate Matter/ Sulfur Oxides - Assessment of Newly Available Health Effects Information | AOCD Addendum | 8-86-020A | 86-221249 |
| Phenol | HIA | 8-86-003F | 86-178076 |
| Phosgene | HAD | 8-86-022A | 87-147039/AS |
| Propylene Oxide | HIA | 8-86-007F | Not yet available |
| Tetrochloroethylene | HAD | 8-82-005F | 85-249704 |

## AVAILABILITY OF ECAO DOCUMENTS (Continued)

| Document Title | Document Type | EPA Number (600/)* | NTIS Number (PB-) |
|---|---|---|---|
| Tetrochloroethylene- Updated Carcinogenicity Assessment | HAD Addendum | 8-82-005FA | 86-174489 |
| Toluene | HAD | 8-82-008F | 84-100056 |
| Trichloroethylene | HAD | 8-82-006F | 85-249696 |
| Vinylidene Chloride | HAD | 8-83-031F | 86-100641 |

* Key:

A = First External Review Draft
B = Second External Review Draft
F = Final
FA = Addendum Review Draft
FF = Addendum Final

---

FOR INFORMATION ON DOCUMENT AVAILABILITY CONTACT:

NATIONAL TECHNICAL INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
5285 PORT ROYAL ROAD
SPRINGFIELD, VIRGINIA 22161
703/487-4650

CENTER FOR ENVIRONMENTAL RESEARCH INFORMATION
U.S. ENVIRONMENTAL PROTECTION AGENCY
26 WEST ST. CLAIR STREET
CINCINNATI, OHIO 45268
513/569-7562 (FTS: 684-7562)

# APPENDIX B

# LISTS OF EXISTING AND PLANNED MUNICIPAL WASTE COMBUSTION FACILITIES

## TABLE B-1. EXISTING FACILITIES ORDERED BY STATE AND DESIGN TYPE

| LOCATION |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
| CITY | STATE | COMBUSTOR TYPE | HEAT RECOVERY | # OF COMBUSTORS | TOTAL PLANT CAPACITY (TPD) | TYPE OF CONTROL(S) | STARTUP DATE | REFERENCES |
| Sitka | AK | MI/SA | YES | 2 | 25 | ESP | 1985 | CITY CURRENTS 10/86 |
| Tuscaloosa | AL | MI/SA | YES | 4 | 300 | ESP | 1984 | CITY CURRENTS 10/86 |
| Hope | AR | MI/SA | NO | 3 | 38 | NONE | NA |  |
| Batesville | AR | MI/SA | YES | 1 | 50 | NONE | 1981 |  |
| Blytheville | AR | MI/SA | NO | 2 | 70 | NONE | 1983 | DIRECT CONTACT TO FACILITY 2/87 |
| Osceola | AR | MI/SA | YES | 2 | 50 | NONE | 1980 |  |
| North Little Rock | AR | MI/SA | YES | 4 | 100 | NONE | 1977 | CITY CURRENTS 10/86 |
| Stuttgart | AR | MI/SA | NO | 3 | 60 | NONE | NA | MRI |
| Hot Springs | AR | MI/SA | NO | 8 | 100 | NONE | NA |  |
| New Canaan | CT | MB/OF | NO | 1 | 108 | VWS | NA |  |
| Stamford I | CT | MB/OF | YES | 1 | 200 | ESP | 1974 | DIRECT CONTACT TO FACILITY 3/87 |
| Stamford II | CT | MB/OF | YES | 1 | 360 | ESP | 1974 | DIRECT CONTACT TO FACILITY 3/87 |
| Windham | CT | MI/SA | YES | 3 | 108 | BAG | 1981 |  |
| Washington(Solid Waste Red.Cent.I) | DC | MB/OF | NO | 4 | 1000 | ESP | 1972 | DIRECT CONTACT TO FACILITY 2/87 |
| Dade Co. | FL | RDF | YES | 4 | 3000 | ESP | 1982 | CITY CURRENTS 10/86, MRI |
| Pinellas Co. | FL | MB/OF | YES | 2 | 2000 | ESP | 1983 | CITY CURRENTS 10/86 |
| Pinellas Co. (Expansion) | FL | MB/OF | YES | 1 | 1150 | ESP | 1986 | CITY CURRENTS 10/86 |
| Tampa | FL | MB/OF | YES | 4 | 1000 | ESP | 1985 |  |
| Mayport Naval Station | FL | MI/EA | YES | 1 | 48 | C | 1978 | CITY CURRENTS 10/86 |
| Lakeland | FL | RDF/C | YES | 3 | 300 | ESP | 1981 | CITY CURRENTS 10/86 |
| Honolulu | HA | MB/OF | NO | 1 | 600 | ESP | 1970 | DIRECT CONTACT TO FACILITY 3/87 |
| Ames | IA | RDF/C | YES | 2 | 200 | ESP | 1975 | DIRECT CALL TO FACILITY 3/87 |
| Cassia County | ID | MI/SA | YES | 2 | 50 | NONE | 1982 |  |
| Chicago (NW Waste to Energy Fac) | IL | MB/OF | YES | 4 | 1600 | ESP | 1970 |  |
| East Chicago | IN | MB/OF | NO | 2 | 450 | VWS | 1971 | DIRECT CONTACT TO FACILITY 3/87 |
| Louisville | KY | MB/OF | NO | 4 | 1000 | WS | NA | MRI |
| Simpson Co. (Franklin) | KY | MI/SA | YES | 2 | 77 | NONE | NA | STATE OF KENTUCKY |
| Shreveport | LA | MB/OF | NO | 1 | 200 | VWS | NA |  |
| Haverhill/Lawrence | MA | RDF | YES | 3 | 1300 | ESP | 1984 | CITY CURRENTS 10/86 |
| Fall River | MA | MB/OF | NO | 2 | 600 | WS | 1972 | DIRECT CONTACT TO FACILITY 3/87 |
| Framingham | MA | MB/OF | NO | 2 | 500 | DS/BAG | 1970 | DIRECT CONTACT TO FACILITY 3/87 |
| North Andover | MA | MB/OF | YES | 2 | 1500 | ESP | 1985 | CITY CURRENTS 10/86 |
| Saugus | MA | MB/OF | YES | 2 | 1500 | ESP | 1985 |  |
| Pittsfield | MA | MI/EA | YES | 3 | 240 | EGB | 1981 |  |
| Baltimore (Pulaski) | MD | MB/OF | NO | 4 | 1200 | ESP | NA |  |
| Baltimore (RESCO) | MD | MB/OF | YES | 3 | 2250 | ESP | 1985 |  |
| Harpswell | ME | MI/SA | NO | 1 | 14 | NONE | NA |  |
| Auburn | ME | MI/SA | YES | 4 | 200 | BAG | 1981 |  |
| Clinton (Grosse Pointe) | MI | MB/OF | NO | 2 | 600 | ESP | NA | MICHIGAN APC |
| S.E. Oakland Co. | MI | MB/OF | NO | 2 | 600 | WS | NA | MICHIGAN APC |
| Duluth | MN | RDF | YES | 2 | 400 | VWS | NA |  |
| Savage | MN | MI/SA | YES | 1 | 60 | ESP | NA | DEPARTMENT OF AIR QUALITY (MN) |
| Purham | MN | MI/SA | YES | 2 | 80 | ESP | 1986 | DEPARTMENT OF AIR QUALITY (MN) |
| Red Wing | MN | MI/SA | YES | 1 | 72 | ESP | 1982 |  |
| Collegeville (St. Johns) | MN | MI/SA | YES | 1 | 50 | WS | 1981 | CITY CURRENTS 10/86 |
| St. Louis (1 and 2) | MO | MB/OF | NO | 4 | 800 | WS | NA |  |
| Fort Leonard Wood | MO | MI/SA | YES | 3 | 75 | NONE | NA |  |
| Pascagoula | MS | MI/SA | YES | 2 | 150 | ESP | 1985 |  |

## TABLE B-1 . EXISTING FACILITIES ORDERED BY STATE AND DESIGN TYPE (Continued)

| LOCATION CITY | STATE | COMBUSTOR TYPE | HEAT RECOVERY | # OF COMBUSTORS | TOTAL PLANT CAPACITY (TPD) | TYPE OF CONTROL(S) | STARTUP DATE | REFERENCES |
|---|---|---|---|---|---|---|---|---|
| Livingston | MT | MI/SA | YES | 2 | 75 | NONE | 1982 | |
| Wilmington | NC | MB/OF | YES | 2 | 200 | ESP | 1984 | |
| Wrightsville | NC | MI/SA | NO | 2 | 50 | NONE | NA | TRIP REPORT |
| Litchfield | NH | MI/SA | NO | 1 | 22 | NONE | NA | |
| Durham | NH | MI/SA | YES | 3 | 108 | C | 1980 | DIRECT CONTACT TO FACILITY 2/87 |
| Wilton | NH | MI/SA | NO | 1 | 30 | NONE | NA | |
| Auburn | NH | MI/SA | NO | 1 | 5 | NONE | NA | |
| Pittsfield | NH | MI/SA | NO | 1 | 48 | NONE | NA | |
| Meredith | NH | MI/SA | NO | 2 | 31 | NONE | NA | |
| Groveton | NH | MI/SA | YES | 1 | 24 | NONE | NA | |
| Portsmouth | NH | MI/SA | YES | 4 | 200 | BAG | 1982 | |
| Nottingham | NH | MI/SA | NO | 1 | 8 | NONE | 1972 | DIRECT CONTACT TO FACILITY 3/87 |
| Candia | NH | MI/SA | NO | 1 | 15 | NONE | NA | |
| Wolfeboro | NH | MI/SA | NO | 2 | 16 | NONE | 1975 | DIRECT CONTACT TO FACILITY 3/87 |
| Canterbury | NH | MI/SA | NO | 1 | 10 | NONE | NA | |
| Albany | NY | RDF | YES | 2 | 600 | ESP | 1981 | |
| Niagra Falls | NY | RDF | YES | 2 | 2200 | ESP | 1981 | |
| Brooklyn (SW) | NY | MB/OF | NO | 3 | 750 | ESP | NA | |
| Glen Cove | NY | MB/OF | YES | 2 | 250 | ESP | 1983 | NEW YORK STATE |
| Westchester Co. | NY | MB/OF | YES | 3 | 2250 | ESP | 1984 | |
| Brooklyn (N.Henry St.) | NY | MB/OF | NO | 1 | 1000 | ESP | NA | |
| Huntington | NY | MB/OF | NO | 3 | 450 | WS | NA | |
| New York (Betts Avenue) | NY | MB/OF | YES | 4 | 1000 | ESP | NA | |
| Skaneateless | NY | MI/SA | NO | 1 | 13 | NONE | 1975 | DIRECT CONTACT TO FACILITY 3/87 |
| Oneida Co. (Rome) | NY | MI/SA | YES | 4 | 200 | NONE | 1985 | |
| Cattaraugus Co. (Cuba) | NY | MI/SA | YES | 3 | 112 | NONE | 1983 | CITY CURRENTS 10/86 |
| Oswego County (Volney) | NY | MI/SA | YES | 4 | 200 | ESP | 1985 | |
| Akron | OH | RDF | YES | 3 | 1000 | ESP | 1979 | |
| Columbus | OH | RDF | YES | 6 | 2000 | ESP | 1983 | |
| N.Dayton | OH | MB/OF | NO | 2 | 600 | ESP | 1970 | |
| S.Dayton | OH | MB/OF | NO | 2 | 600 | ESP | 1970 | |
| Euclid | OH | MB/OF | NO | NA | 200 | ESP | NA | STATE OF OHIO |
| Tulsa | OK | MB/OF | YES | 2 | 750 | ESP | 1986 | |
| Miami | OK | MI/SA | YES | 3 | 108 | NONE | 1982 | DIRECT CONTACT TO FACILITY 2/87 |
| Marion County | OR | MB/OF | YES | 2 | 550 | DS/BAG | 1986 | |
| Philadelphia (Northwest Unit) | PA | MB/OF | NO | 2 | 750 | ESP | 1957 | DIRECT CONTACT TO FACILITY 3/87 |
| Philadelphia (E.Central Unit) | PA | MB/OF | NO | 2 | 750 | ESP | 1965 | DIRECT CONTACT TO FACILITY 3/87 |
| Harrisburg | PA | MB/OF | YES | 2 | 720 | ESP | 1973 | |
| Johnsonville | SC | MI/SA | YES | 1 | 50 | NONE | NA | |
| Hampton | SC | MI/SA | YES | 3 | 270 | ESP | 1985 | CONSUMAT |
| Nashville | TN | MB/OF | YES | 2 | 720 | ESP | 1974 | CITY CURRENTS 10/86 |
| Nashville (Expansion) | TN | MB/OF | YES | 1 | 400 | ESP | 1986 | CITY CURRENTS 10/86 |
| Gallatin | TN | MB/RC | YES | 2 | 200 | ESP | 1981 | DIRECT CONTACT TO FACILITY 2/87 |
| Dyersburg | TN | MI/SA | YES | 1 | 100 | NONE | 1980 | CITY CURRENTS 10/86 |
| Lewisburg | TN | MI/SA | YES | 1 | 60 | WS | 1980 | CITY CURRENTS 10/86 |
| Cleburne | TX | MI/SA | YES | 3 | 115 | ESP | 1986 | STATE OF TEXAS, CITY CURRENTS 10/86 |
| Carthage City | TX | MI/SA | YES | 1 | 36 | NONE | 1985 | STATE OF TEXAS |
| Gatesville | TX | MI/SA | YES | 1 | 20 | NONE | NA | |

## TABLE B-1. EXISTING FACILITIES ORDERED BY STATE AND DESIGN TYPE (Continued)

| LOCATION | | | | | TOTAL | | | |
|---|---|---|---|---|---|---|---|---|
| CITY | STATE | COMBUSTOR TYPE | HEAT RECOVERY | # OF COMBUSTORS | PLANT CAPACITY (TPD) | TYPE OF CONTROL(S) | STARTUP DATE | REFERENCES |
| Center | TX | MI/SA | YES | 1 | 36 | NONE | 1985 | STATE OF TEXAS |
| Palestine | TX | MI/SA | YES | 1 | 28 | WS | NA | |
| Waxahachie | TX | MI/SA | YES | 2 | 50 | WS | 1982 | CITY CURRENTS 10/86 |
| Ogden | UT | MB/OF | YES | 3 | 450 | ESP | NA | |
| Portsmouth | VA | MB/OF | YES | 2 | 160 | ESP | 1971 | |
| Norfolk (Navy Station) | VA | MB/OF | YES | 2 | 360 | ESP | 1967 | |
| Hampton | VA | MB/OF | YES | 2 | 200 | ESP | 1980 | |
| Harrisonburg | VA | MB/OF | YES | 2 | 100 | ESP | 1982 | |
| Galax | VA | MB/RC | YES | 1 | 56 | BAG | NA | CITY CURRENTS 10/86 |
| Salem | VA | MI/SA | YES | 4 | 100 | NONE | 1970 | |
| Newport News (Ft. Eustis) | VA | MI/SA | YES | 1 | 35 | NONE | 1980 | |
| Bellingham | WA | MI/EA | YES | 1 | 100 | NONE | 1986 | |
| Bellingham | WA | MI/SA | YES | 2 | 100 | NONE | 1986 | |
| Sheboygan | WI | MB/OF | NO | 2 | 240 | WS | NA | STATE OF WISCONSIN |
| Waukesha | WI | MB/OF | YES | 2 | 175 | ESP | 1971 | |
| Barron County | WI | MI/SA | NO | 2 | 80 | ESP | 1986 | STATE OF WISCONSIN |
| Madison | WI | RDF/C | YES | 2 | 400 | ESP/C | 1979 | CITY CURRENTS 10/86 |

KEY

COMBUSTOR TYPES:
MI/SA = MODULAR COMBUSTOR WITH STARVED AIR
MI/EA = MODULAR COMBUSTOR WITH EXCESS AIR (VICON)
RDF = REFUSE DERIVED FUEL FIRED IN DEDICATED BOILER
RDF/C = REFUSE DERIVED FUEL/COAL COFIRING
MB/OF = MASS BURN WITH OVERFEED STOKER
MB/RC = MASS BURN IN ROTARY COMBUSTOR

TYPES OF CONTROLS:
C = CYCLONE
ESP = ELECTROSTATIC PRECIPITATOR
WS = WET SCRUBBER
DS = DRY SCRUBBER
VWS = VENTURI WET SCRUBBER
BAG = BAGHOUSE
EGB = ELECTROSTATIC GRAVEL BED

NA = DATA NOT AVAILABLE OR TECHNOLOGY UNDECIDED

## TABLE B-2. PLANNED FACILITIES ORDERED BY STATE AND DESIGN TYPE

| LOCATION | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| CITY | STATE | COMBUSTOR TYPE | HEAT RECOVERY | TOTAL PLANT CAPACITY (TPD) | STARTUP DATE | STATUS CODE | CONTROL STATUS | REFERENCES |
| JUNEAU | AK | MI/SA | YES | 70 | NA | 3 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| HUNTSVILLE | AL | MB/OF | YES | 690 | 1989 | 4 | NA | CITY CURRENTS, 10/86 |
| FAYETTEVILLE | AR | MB/OF | YES | 150 | NA | 3 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| SAN DIEGO (SANDER) | CA | MB/OF | YES | 2250 | 1989 | 2 | NA | CITY CURRENTS 10/86 |
| DOWNEY | CA | MB/OF | YES | 200 | NA | 3 | NA | McILVANE 5/86 |
| LOS ANGELES CO. (PUENTE HILLS E) | CA | MB/OF | YES | 2000 | NA | 2 | NA | WASTE AGE |
| LOS ANGELES CO. (PUENTE HILLS W) | CA | MB/OF | YES | 2000 | NA | 2 | NA | CWMB |
| SAN MARCOS (SAN DIEGO CO.) | CA | MB/OF | YES | 1672 | 1989 | 4 | NA | CITY CURRENTS 10/86 |
| LOS ANGELES CO. (SPADRA) | CA | MB/OF | YES | 1000 | NA | 1 | NA | CWMB |
| CITY OF COMMERCE (LOS ANGELES CO.) | CA | MB/OF | YES | 300 | 1987 | 4 | NA | CITY CURRENTS 10/86 |
| UKIAH | CA | MB/OF | YES | 100 | 1987 | 2 | NA | CITY CURRENTS 10/86 |
| IRWINDALE | CA | MB/OF | YES | 3000 | 1989 | 3 | NA | McILVANE 5/86 |
| VISALIA | CA | MB/OF | YES | 350 | 1990 | 1 | NA | SCAMD SUBMITTAL |
| BRISBANE | CA | MB/OF | YES | 1500 | NA | 1 | NA | |
| SOUTH GATE (LOS ANGELES) | CA | MB/OF | YES | 375 | 1990 | 1 | NA | McILVANE 5/86 |
| FRESNO COUNTY | CA | MB/OF | YES | 600 | NA | 3 | NA | U.S. EPA |
| SANTA CLARA | CA | MB/OF | YES | 400 | NA | 3 | NA | McILVANE 5/86 |
| STANISLAUS COUNTY | CA | MB/OF | YES | 800 | 1989 | 4 | NA | CITY CURRENTS 10/86 |
| GARDENA | CA | MB/OF | YES | 1200 | 1991 | 3 | NA | U.S. EPA |
| LONG BEACH, STAGE I | CA | MB/OF | YES | 920 | 1988 | 4 | NA | WASTE AGE |
| LONG BEACH, STAGE II | CA | MB/OF | YES | 1350 | NA | 3 | NA | SCAMD SUBMITTAL |
| LANCER (LOS ANGELES) | CA | MB/OF | YES | 1600 | 1989 | 3 | NA | U.S. EPA |
| WILMINGTON | CA | MB/RC | YES | 2000 | 1988 | 4 | NA | McILVANE 5/86 |
| VENTURA COUNTY | CA | MB/RC | YES | 1000 | NA | 0 | NA | U.S. EPA |
| SANGER | CA | MB/RC | YES | 500 | 1987 | 2 | NA | McILVANE 5/86 |
| FREMONT | CA | MI/EA | YES | 480 | 1989 | 4 | NA | CITY CURRENTS 10/86 |
| PLEASANTON | CA | MI/SA | YES | 100 | NA | 2 | NA | McILVANE 5/86 |
| SANTA CRUZ | CA | NA | YES | 175 | NA | 1 | NA | FRANKLIN |
| ALAMEDA | CA | NA | YES | 1600 | 1989 | 2 | NA | McILVANE 5/86 |
| RIVERSIDE | CA | NA | YES | 1500 | 1990 | 1 | NA | SCAMD SUBMITTAL |
| LOS GATOS | CA | RDF | YES | 200 | NA | 5 | NA | EPA REGION IV |
| SACRAMENTO COUNTY | CA | RDF | YES | 700 | NA | 1 | NA | |
| CONCORD | CA | RDF | YES | 900 | 1989 | 1 | NA | SCAMD SUBMITTAL |
| REDWOOD (SAN FRANCISCO) | CA | RDF | YES | 3850 | NA | 3 | NA | CWMB |
| SAN BERNARDINO | CA | RDF | YES | 1600 | 1989 | 3 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| MILLIKEN LANDFILL | CA | RDF | YES | 1600 | NA | 2 | NA | CWMB |
| AZUSA | CA | RDF | YES | 2000 | 1989 | 1 | NA | McILVANE 5/86 |
| CONTRA COSTA COUNTY (RICHMOND) | CA | RDF | YES | 900 | 1989 | 1 | NA | WASTE AGE |
| COMPTON | CA | RDF | YES | 1800 | NA | 2 | NA | WASTE AGE |
| NEW MILFORD | CT | MB/OF | YES | 750 | NA | 1 | NA | WASTE TO ENERGY |
| MIDDLETOWN | CT | MB/OF | YES | 230 | 1989 | 4 | DS/BG | McILVANE 5/86 |
| BRIDGEPORT | CT | MB/OF | YES | 2250 | 1988 | 4 | DS/BG | CITY CURRENTS 10/86 |
| WATERBURY | CT | MB/OF | YES | 360 | 1989 | 1 | NA | EPA REGION VII SUBMITTAL |
| BRISTOL | CT | MB/OF | YES | 650 | 1988 | 4 | DS/BG | CITY CURRENTS 10/86 |
| PRESTON | CT | MB/OF | YES | 600 | 1990 | 3 | NA | SCAMD SUBMITTAL |
| WALLINGFORD | CT | MI/EA | YES | 420 | 1988 | 4 | DS/BG | CITY CURRENTS 10/86 |
| NEW HAVEN | CT | MI/SA | YES | 450 | 1989 | 4 | DS/BG | McILVANE 5/86 |
| DANBURY | CT | NA | YES | 450 | 1990 | 0 | NA | FRANKLIN |
| STRATFORD | CT | NA | YES | 360 | 1989 | 4 | NA | CITY CURRENTS 10/86 |

## TABLE B-2. PLANNED FACILITIES ORDERED BY STATE AND DESIGN TYPE (Continued)

| LOCATION<br>CITY | STATE | COMBUSTOR TYPE | HEAT RECOVERY | TOTAL PLANT CAPACITY (TPD) | STARTUP DATE | STATUS CODE | CONTROL STATUS | REFERENCES |
|---|---|---|---|---|---|---|---|---|
| HARTFORD | CT | RDF | YES | 2000 | 1988 | 4 | DS/BG | WASTE TO ENERGY |
| WILMINGTON (DELAWARE SWA) | DE | RDF | YES | 600 | 1987 | 4 | NA | EPA REGION IV SUBMITTAL |
| OKALOOSA | FL | MB/OF | YES | 450 | NA | 1 | NA | STATE OF FLORIDA |
| HILLSBOROUGH COUNTY | FL | MB/OF | YES | 1200 | 1987 | 4 | ESP | CITY CURRENTS 10/86 |
| JACKSONVILLE (DUVAL COUNTY) | FL | MB/OF | YES | 2700 | 1990 | 1 | NA | STATE OF FLORIDA |
| PASCO CO. | FL | MB/OF | YES | 1200 | NA | 1 | NA | STATE OF FLORIDA |
| MONROE CO. (KEY WEST) | FL | MB/OF | YES | 150 | 1987 | 4 | ESP | STATE OF FLORIDA |
| ESCAMBIA | FL | MB/OF | YES | 400 | NA | 3 | NA | STATE OF FLORIDA |
| PANAMA CITY (BAY COUNTY) | FL | MB/RC | YES | 510 | 1987 | 4 | ESP | CITY CURRENTS 10/86 |
| BROWARD COUNTY (SOUTH) | FL | NA | YES | 2250 | 1989 | 4 | ESP/S | CITY CURRENTS 10/86 |
| BROWARD COUNTY (NORTH) | FL | NA | YES | 2200 | 1989 | 4 | ESP/S | CITY CURRENTS 10/86 |
| LAKE COUNTY (PROJECT 1) | FL | NA | YES | 250 | 1988 | 2 | ESP | McILVANE 5/86 |
| LAKE COUNTY (PROJECT 2) | FL | NA | YES | 250 | 1988 | 2 | NA | McILVANE 5/86 |
| WEST PALM BEACH COUNTY | FL | RDF | YES | 2000 | 1989 | 4 | NA | CITY CURRENTS 10/86 |
| NAPLES (COLLIER COUNTY) | FL | RDF | YES | 860 | 1988 | 4 | BH | EPA REGIONAL SUBMITTAL |
| SAVANNAH | GA | MB/OF | YES | 500 | 1987 | 4 | NA | CITY CURRENTS 10/86 |
| HONOLULU | HA | RDF | YES | 1800 | 1989 | 4 | NA | CITY CURRENTS 10/86 |
| SANGAMON CO. (SPRINGFIELD) | IL | NA | YES | 450 | NA | 3 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| JEFFERSON CO. (MT. VERNON) | IL | NA | YES | 300 | NA | 3 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| INDIANAPOLIS | IN | MB/OF | YES | 2360 | 1989 | 4 | NA | CITY CURRENTS 10/86 |
| BLOOMINGTON | IN | MB/RC | YES | 370 | 1988 | 4 | NA | CITY CURRENTS 10/86 |
| FORT KNOX | KY | MI/SA | YES | 40 | NA | 4 | NA | McILVANE 5/86 |
| CAMPBELLSVILLE | KY | MI/SA | YES | 100 | NA | 1 | NA | CITY CURRENTS 10/86 |
| HOLYOKE | MA | MB/OF | YES | 685 | 1989 | 3 | AG | McILVANE 5/86 |
| MILLBURY | MA | MB/OF | YES | 1500 | 1988 | 4 | ESP/AG | CITY CURRENTS, 10/86 |
| LOWELL | MA | MB/OF | YES | 750 | NA | 1 | NA | U.S. EPA |
| DORCHESTER | MA | MB/OF | YES | 1500-1800 | NA | 1 | ESP/DS | U.S. EPA |
| PLAINVILLE | MA | MB/OF | YES | 2000 | NA | 1 | NA | U.S. EPA |
| WEBSTER | MA | MI/EA | YES | 360 | 1989 | 4 | NA | CITY CURRENTS 10/86 |
| SPRINGFIELD (AGAWAM) | MA | MI/EA | YES | 360 | 1988 | 3 | DS/BH/AG | McILVANE 5/86 |
| NANTUCKET | MA | MI/SA | YES | 75 | 1987 | 0 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| SOMERVILLE | MA | RDF | YES | 330 | NA | 1 | NA | U.S. EPA |
| ROCHESTER | MA | RDF | YES | 1800 | 1989 | 4 | ESP/AG | CITY CURRENTS 10/86 |
| WEYMOUTH | MA | RDF/FB | YES | 400 | NA | 1 | NA | WASTE TO ENERGY 8/28/85 |
| MONTGOMERY CO. | MD | MB/OF | YES | 1800 | NA | 1 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| HOWARD CO. (BALTIMORE) | MD | MB/OF | YES | 1000-1500 | NA | 3 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| EDGEWOOD (HARFORD COUNTY) | MD | MI/SA | YES | 360 | 1987 | 4 | NA | EPA REGION III SUBMITTAL |
| ANNE ARUNDEL CO. | MD | NA | YES | 500 | NA | 3 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| AUGUSTA (BATH/BRUNSWICK & AUGUSTA) | ME | MB/OF | YES | 500 | 1989 | 4 | NA | CITY CURRENTS 10/86 |
| PORTLAND | ME | MB/OF | YES | 500 | 1988 | 4 | ESP/AG | CITY CURRENTS 10/86 |
| LEWISTON | ME | MB/OF | YES | 300 | NA | 1 | NA | McILVANE 5/86 |
| BANGOR/BREWER/ORRINGTON | ME | RDF | YES | 750 | 1988 | 4 | BH/AG | CITY CURRENTS 10/86 |
| BIDDEFORD/SACO | ME | RDF | YES | 607 | 1987 | 4 | AG | CITY CURRENTS 10/86 |
| JACKSON COUNTY | MI | MB/OF | YES | 200 | 1987 | 3 | DS/BH | McILVANE 5/86 |
| WAYNE CO. (DEARBON HEIGHTS) | MI | MB/OF | YES | 800 | NA | 1 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| LITCHFIELD | MI | MI/SA | YES | 75 | NA | 0 | AG | MICHIGAN APC |
| MUSKIGON | MI | MI/SA | YES | 150 | NA | 4 | DS/BH | MICHIGAN APC |
| DETROIT | MI | RDF | YES | 3300 | 1988 | 2 | NA | CITY CURRENTS 10/86 |
| HENNEPIN COUNTY (MINNEAPOLIS) | MN | MB/OF | YES | 1200 | 1989 | 4 | BH/AG | CITY CURRENTS 10/86 |

## TABLE B-2. PLANNED FACILITIES ORDERED BY STATE AND DESIGN TYPE (Continued)

| LOCATION | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| CITY | STATE | COMBUSTOR TYPE | HEAT RECOVERY | TOTAL PLANT CAPACITY (TPD) | STARTUP DATE | STATUS CODE | CONTROL STATUS | REFERENCES |
| PERHAM | MN | MI/SA | YES | 72 | 1986 | 4 | ESP | McILVANE 5/86, WASTE AGE 11/86 |
| OLMSTEAD CO. | MN | NA | YES | 200 | NA | 4 | ESP | McILVANE 5/86, WASTE AGE 11/86 |
| POPE AND DOUGLAS COUNTIES | MN | NA | YES | 100 | NA | 3 | ESP | McILVANE 5/86, WASTE AGE 11/86 |
| MANKATO (1 & 2) | MN | RDF | YES | 940 | 1987 | 3 | ESP | McILVANE 5/86, WASTE AGE 11/86 |
| NEWPORT | MN | RDF | YES | 1000 | 1987 | 4 | BH/AG | CITY CURRENTS 10/86 |
| RED WING (1 & 2) | MN | RDF | YES | 940 | 1987 | 3 | ESP | McILVANE 5/86, WASTE AGE 11/86 |
| ST. LOUIS | MO | MB/RC | YES | 600 | 1989 | 3 | NA | CITY CURRENTS 10/86, CITY OF ST. LOUIS |
| CHARLOTTE | NC | MB/OF | YES | 200 | NA | 2 | NA | STATE OF NORTH CAROLINA |
| GREENSBORO | NC | MB/RC | YES | 400 | NA | 2 | NA | STATE OF NORTH CAROLINA |
| WILLISTON | ND | MB/OF | YES | 100 | NA | 3 | NA | CITY CURRENTS 10/86 |
| PORTSMOUTH | NH | MB/OF | YES | 800 | NA | 3 | BH | McILVANE 5/86, WASTE AGE 11/86 |
| CLAREMONT | NH | MB/OF | YES | 200 | 1987 | 4 | NA | CITY CURRENTS 10/86 |
| CONCORD | NH | MB/OF | YES | 400 | 1987 | 3 | NA | McILVANE 5/86 |
| MANCHESTER | NH | MI/EA | YES | 450 | 1989 | 4 | NA | CITY CURRENTS 10/86 |
| DERRY | NH | NA | YES | 400 | 1988 | 3 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| CONWAY | NH | NA | YES | 150 | NA | 3 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| WARREN COUNTY | NJ | MB/OF | YES | 400 | 1988 | 4 | NA | CITY CURRENTS 10/86 |
| PENNSAUKEN | NJ | MB/OF | YES | 500 | 1989 | 3 | NA | McILVANE 5/86 |
| ATLANTIC CO. (LITTLE EGG HARBOR) | NJ | MB/OF | YES | 750 | 1990 | 3 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| HUDSON COUNTY | NJ | MB/OF | YES | 1500 | 1989 | 3 | NA | McILVANE 5/86 |
| GLOUCESTER COUNTY | NJ | MB/OF | YES | 575 | 1989 | 2 | NA | CITY CURRENTS 10/86 |
| CARTERET | NJ | MB/OF | YES | 3000 | NA | 3 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| CAMDEN COUNTY | NJ | MB/OF | YES | 1000 | 1989 | 3 | NA | McILVANE 5/86 |
| ESSEX COUNTY | NJ | MB/OF | YES | 2250 | 1989 | 4 | ESP/S | CITY CURRENTS 10/86 |
| PASSAIC COUNTY | NJ | MB/OF | YES | 1400 | 1989 | 3 | NA | McILVANE 5/86 |
| BERGEN COUNTY | NJ | MB/OF | YES | 3000 | 1990 | 4 | NA | CITY CURRENTS 10/86 |
| OCEAN CO. | NJ | MB/OF | YES | 1000 | 1992 | 0 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| CAPE MAY | NJ | MB/OF | YES | 300 | 1990 | 1 | NA | McILVANE 5/86 |
| FORT DIX | NJ | MI/SA | YES | 80 | 1988 | 4 | BH/S | CITY CURRENTS 10/86 |
| UNION CO. (RAHWAY) | NJ | NA | YES | 1500 | 1990 | 0 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| HUNTERDON CO. | NJ | NA | YES | 300-500 | NA | 0 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| EDISON TOWNSHIP | NJ | NA | YES | 3000 | 1989 | 1 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| SUSSEX CO. (LAFAYETTE) | NJ | NA | YES | 400 | NA | 1 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| SOMERSET CO. (BRIDGEWATER) | NJ | NA | YES | 600 | 1988 | 0 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| MERCER CO. (HAMILTON TOWNSHIP) | NJ | NA | YES | 1200 | NA | 0 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| MORRIS COUNTY | NJ | RDF | YES | 1000 | NA | 1 | NA | WASTE TO ENERGY 9/25/85 |
| RENO (PHASE II) | NV | RDF | YES | 1000 | NA | 4 | NA | CITY CURRENTS 10/86 |
| HUDSON FALLS (WASHINGTON COUNTY) | NY | MB/OF | YES | 400 | 1988 | 3 | DS/ESP | CITY CURRENTS 10/86 |
| ONTARIO CO. (WESTERN FINGER LAKES) | NY | MB/OF | YES | 600 | NA | 1 | NA | STATE OF NEW YORK |
| HUNTINGTON | NY | MB/OF | YES | 750 | 1990 | 2 | NA | STATE OF NEW YORK |
| BABYLON | NY | MB/OF | YES | 750 | 1988 | 4 | DS/BH | CITY CURRENTS 10/86 |
| OYSTER BAY | NY | MB/OF | YES | 1650 | 1989 | 4 | ESP | McILVANE 5/86 |
| ST. LAWRENCE COUNTY | NY | MB/OF | YES | 225 | 1989 | 3 | NA | CITY CURRENTS 10/86 |
| NEW YORK (BROOKLYN NAVY YARD) | NY | MB/OF | YES | 3000 | 1989 | 2 | DS/BH | WASTE TO ENERGY 10/23/85 |
| LONG BEACH | NY | MB/OF | YES | 200 | 1988 | 4 | ESP | STATE OF NEW YORK |
| NORTH HEMPSTEAD | NY | MB/OF | YES | 1000 | 1990 | 2 | NA | STATE OF NEW YORK |
| SOUTH BRONX | NY | MB/OF | YES | 800 | NA | 3 | BH/S | McILVANE 5/86 |
| ONONDAGA COUNTY (SYRACUSE) | NY | MB/OF | YES | 1400 | NA | 2 | NA | WASTE AGE 11/86 |
| HEMPSTEAD | NY | MB/OF | YES | 2250 | 1989 | 2 | DS/ESP | CITY CURRENTS 10/86 |

## TABLE B-2. PLANNED FACILITIES ORDERED BY STATE AND DESIGN TYPE (Continued)

| LOCATION |  |  |  | TOTAL PLANT |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
| CITY | STATE | COMBUSTOR TYPE | HEAT RECOVERY | CAPACITY (TPD) | STARTUP DATE | STATUS CODE | CONTROL STATUS | REFERENCES |
| BROOME COUNTY | NY | MB/OF | YES | 500 | 1991 | 3 | NA | McILVANE 5/86 |
| DUTCHESS COUNTY | NY | MB/RC | YES | 400 | 1987 | 4 | BH | CITY CURRENTS 10/86 |
| ISLIP | NY | MB/RC | YES | 518 | 1988 | 4 | ESP | EPA REGION IV SUBMITTAL |
| GREENE COUNTY | NY | MI/SA | YES | 300 | NA | 1 | NA | EPA REGION IV SUBMITTAL |
| ERIE COUNTY | NY | MI/SA | YES | 250 | NA | 1 | NA | EPA REGION IV SUBMITTAL |
| GENESEE COUNTY | NY | MI/SA | YES | 100 | NA | 1 | NA | WASTE AGE 11/86 |
| BRONX (BARRETTO POINT) | NY | NA | YES | 2000 | NA | 2 | NA | STATE OF NEW YORK |
| MANHATTAN(SHERMAN CREEK) | NY | NA | YES | 1200 | NA | 2 | NA | STATE OF NEW YORK |
| STATEN ISLAND | NY | NA | YES | 3000 | NA | 2 | NA | STATE OF NEW YORK |
| QUEENS(MASPETH) | NY | NA | YES | 1200 | NA | 2 | NA | STATE OF NEW YORK |
| SARATOGA CO. | NY | NA | YES | 360 | NA | 2 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| MONTGOMERY COUNTY | OH | MB/OF | YES | 300 | 1987 | 4 | NA | CITY CURRENTS 10/86 |
| FRANKLIN | OH | RDF | YES | 150 | 1987 | 3 | NA | U.S. EPA |
| PORTLAND | OR | MB/OF | YES | 1200 | 1990 | 1 | NA | McILVANE 5/86 |
| YORK COUNTY | PA | MB/OF | YES | 1000 | 1989 | 1 | NA | EPA REGION III SUBMITTAL |
| HANOVER BOROUGH | PA | MB/OF | YES | 200 | NA | 1 | NA | EPA REGION III SUBMITTAL |
| CHESTER | PA | MB/OF | YES | 1200 | 1988 | 3 | NA | EPA REGION III SUBMITTAL |
| BERKS COUNTY | PA | MB/OF | YES | 1200 | 1988 | 1 | NA | McILVANE 5/86 |
| MONTGOMERY COUNTY | PA | MB/OF | YES | 1200 | 1989 | 4 | NA | CITY CURRENTS 10/86 |
| SOUTHWEST BUCKS | PA | MB/OF | YES | 200 | NA | 1 | NA | WASTE TO ENERGY 12/85 |
| CENTRAL BUCKS | PA | MB/OF | YES | 150 | NA | 1 | NA | EPA REGION III SUBMITTAL |
| DELAWARE COUNTY (RESOURCE REC. 2) | PA | MB/OF | YES | 1500 | NA | 1 | NA | McILVANE 5/86 |
| MIFFLIN COUNTY (LEWISTOWN) | PA | MB/OF | YES | 100 | NA | 1 | NA | McILVANE 5/86 |
| BUCKS COUNTY (FALLS TOWNSHIP) | PA | MB/OF | YES | 2200 | NA | 1 | NA | McILVANE 5/86 |
| MERCER COUNTY | PA | MB/OF | YES | 250 | NA | 1 | NA | WASTE TO ENERGY 10/23/85 |
| UPPER BUCKS | PA | MB/OF | YES | 200 | NA | 1 | NA | EPA REGION III SUBMITTAL |
| LEHIGH VALLEY | PA | MB/OF | YES | 1050 | 1989 | 3 | NA | EPA REGION III SUBMITTAL |
| EPHRATA BOROUGH | PA | MB/OF | YES | 1250 | 1990 | 1 | NA | EPA REGION III SUBMITTAL |
| LOWER LUZERNE COUNTY | PA | MB/OF | YES | 100 | NA | 1 | NA | EPA REGION III SUBMITTAL |
| PHILADELPHIA (SOUTH) | PA | MB/OF | YES | 2200 | NA | 1 | NA | McILVANE 5/86 |
| LANCASTER COUNTY | PA | MB/OF | YES | 1000 | 1990 | 1 | NA | EPA REGION III SUBMITTAL |
| MONROE COUNTY (EAST STRAUSBURG) | PA | MI/SA | YES | 300 | 1987 | 1 | NA | EPA REGION III SUBMITTAL |
| CLINTON COUNTY (LOCKHAVEN) | PA | MI/SA | YES | 200 | NA | 1 | NA | McILVANE 5/86 |
| POTTER COUNTY | PA | MI/SA | YES | 25 | NA | 1 | NA | EPA REGION III SUBMITTAL |
| WESTMORELAND COUNTY | PA | MI/SA | YES | 50 | 1986 | 5 | NA | CITY CURRENTS 10/86 |
| MORGANTOWN | PA | NA | YES | 600-750 | NA | 0 | NA | EPA REGION III SUBMITTAL |
| NORTH PENN | PA | NA | YES | 200 | NA | 1 | NA | EPA REGION III SUBMITTAL |
| YORK | PA | NA | YES | 1000 | 1989 | 3 | NA | McILVANE 5/86 |
| ERIE | PA | RDF | YES | 847 | 1988 | 2 | NA | CITY CURRENTS 10/86 |
| NORTHERN TIER SOLID WASTE AUTHORITY | PA | RDF | YES | 100 | NA | 1 | NA | CALIFORNIA WASTE MANAGEMENT SURVEY |
| SAN JUAN | PR | MB/RC | YES | 1000 | NA | 1 | NA | McILVANE 5/86 |
| QUONSET INDUSTRIAL PK | RI | MB/OF | YES | 710 | 1990 | 4 | NA | CITY CURRENTS 10/86 |
| JOHNSTON | RI | MB/RC | YES | 710 | NA | 3 | NA | STATE OF RHODE ISLAND |
| WOONSOCKET | RI | MB/RC | YES | 710 | NA | 3 | NA | STATE OF RHODE ISLAND |
| CHARLESTON | SC | MB/OF | YES | 600 | 1988 | 3 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| KNOX CO.(KNOXVILLE) | TN | NA | YES | 1200 | 1991 | 1 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| HOUSTON (PASADENA) | TX | MB/OF | YES | 1500 | 1990 | 3 | NA | WASTE AGE |
| AUSTIN | TX | MB/OF | YES | 550 | 1989 | 3 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| LUBBOCK | TX | MB/RC | YES | 500 | 1987 | 3 | NA | McILVANE 5/86 |

## TABLE B-2. PLANNED FACILITIES ORDERED BY STATE AND DESIGN TYPE (Continued)

| LOCATION |  | COMBUSTOR TYPE | HEAT RECOVERY | TOTAL PLANT CAPACITY (TPD) | STARTUP DATE | STATUS CODE | CONTROL STATUS | REFERENCES |
|---|---|---|---|---|---|---|---|---|
| CITY | STATE |  |  |  |  |  |  |  |
| CORPUS CHRISTI | TX | NA | YES | 550 | NA | 1 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| GALVESTON | TX | NA | YES | 200 | 1992 | 3 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| GRAND PRAIRIE(IRVING) | TX | NA | YES | 700-800 | NA | 1 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| ALEXANDRIA/ARLINGTON | VA | MB/OF | YES | 975 | 1987 | 4 | NA | CITY CURRENTS 10/86 |
| FAIRFAX COUNTY | VA | NA | YES | 3000 | 1990 | 2 | NA | McILVANE 5/86 |
| PETERSBURG | VA | RDF | YES | 2400 | 1986 | 4 | NA | CITY CURRENTS 10/86 |
| PORTSMOUTH | VA | RDF/C | YES | 2000 | 1987 | 4 | NA | CITY CURRENTS 10/86 |
| RUTLAND | VT | MI/EA | YES | 240 | 1987 | 4 | ESP | CITY CURRENTS 10/86 |
| LYNDONVILLE | VT | NA | YES | 200 | NA | 3 | NA | McILVANE 5/86, WASTE AGE 11/86 |
| SPOKANE COUNTY | WA | MB/OF | YES | 1000 | 1990 | 2 | NA | McILVANE 5/86 |
| SNOHOMISH COUNTY | WA | MB/OF | YES | 1500 | 1992 | 1 | NA | WASTE TO ENERGY 9/25/85 |
| SKAGET COUNTY | WA | MB/RC | YES | 150 | 1988 | 2 | NA | WASTE AGE |
| KING COUNTY | WA | NA | YES | 2000 | 1993 | 1 | NA | EPA REGION X |
| TACOMA | WA | RDF | YES | 500 | 1988 | 4 | NA | FRANKLIN |

KEY

COMBUSTOR TYPES:
MI/SA = MODULAR COMBUSTOR WITH STARVED AIR
MI/EA = MODULAR COMBUSTOR WITH EXCESS AIR (VICON)
RDF = REFUSE DERIVED FUEL FIRED IN DEDICATED BOILER
RDF/C = REFUSE DERIVED FUEL/COAL COFIRING
MB/OF = MASS BURN WITH OVERFEED STOKER
MB/RC = MASS BURN IN ROTARY COMBUSTOR
NA = DATA NOT AVAILABLE OR TECHNOLOGY UNDECIDED

STATUS CODE:
0 = STATUS UNKNOWN
1 = EARLY PLANNING STAGES
2 = PERMITTING STAGES
3 = CONTRACT AWARDED
4 = CONSTRUCTION UNDERWAY OR EXPECTED SOON
5 = TESTING STAGES

CONTROL STATUS:
BH = BAGHOUSE
S = WATER SCRUBBER
ESP = ELECTROSTATIC PRECIPITATOR
AG = ACID GAS CONTROL
DS = DRY SCRUBBER

# APPENDIX C*

## SUMMARY MATRICES OF EMISSIONS TEST DATA

---

*The information presented in this appendix is from Reference 16, Municipal Waste Combustion Study: Emissions Data Base for Municipal Waste Combustors.

## TABLE C-1. OVERVIEW OF EMISSION DATA BASE

| Facility name | Test condition | Criteria pollutants | Acid gases | Metals | Organics |
|---|---|---|---|---|---|
| Mass burn[a] | | | | | |
| Waterwall[b] | | | | | |
| ESP[c] | | | | | |
| Baltimore | Normal[d] | X | | X | |
| Braintree | Normal | X | | X | |
| Chicago | Normal | X | | X | X |
| Hampton (1981) | Normal | X | X | | X |
| Hampton (1982) | Normal | X | X | X | X |
| Hampton (1983) | Normal | X | | | X |
| Hampton (1984) | Normal | X | | | X |
| Peekskill (4/85) | Normal | X | | | X |
| Tulsa (Unit 1) | Normal | X | X | X | X |
| Tulsa (Unit 2) | Normal | X | X | X | X |
| CYC/FF | | | | | |
| Gallatin | Normal | X | X | X | |
| ESP/WS | | | | | |
| Kure | Normal | X | X | X | |
| SD/ESP | | | | | |
| Munich | MSW only[e] | X | X | X | |
| CYC/DI/ESP/FF | | | | | |
| Malmo | Normal | X | X | X | |
| WSH/DI/FF | | | | | |
| Quebec | 110[f] | X | X | X | X |
| Quebec | 125[f] | X | X | X | X |
| Quebec | 140[g] | X | X | X | X |
| Quebec | 200[f] | X | X | X | X |
| Wurzburg | Normal | X | X | X | X |
| SD/FF | | | | | |
| Marion County | Normal | X | X | X | X |
| Quebec | 140[g] | X | X | X | X |
| Quebec | 140 & R[h] | X | X | X | X |
| Refractory | | | | | |
| ESP | | | | | |
| Philadelphia (NW1) | Normal | X | X | | X |
| Philadelphia (NW2) | Normal | X | X | | X |
| CYC/ESP | | | | | |
| Washington, D.C. | Normal | | | X | |
| CYC | | | | | |
| Mayport | MSW/waste oil[i] | X | X | | X |
| WS | | | | | |
| Alexandria | Normal | | | X | |
| Nicosia | Normal | | | X | |
| SD/FF | | | | | |
| Tsushima | Normal | X | X | X | |
| EGB | | | | | |
| Pittsfield | Experimental[j] | | | | X |
| Starved air | | | | | |
| No controls | | | | | |
| Cattaraugus County | Normal | | | | X |
| Dyersburg | Normal | X | X | X | X |
| N. Little Rock | Normal | X | | X | |
| Prince Edward Island | Normal | X | X | X | X |
| Prince Edward Island | Long[k] | X | X | X | X |
| Prince Edward Island | High[l] | X | X | X | X |
| Prince Edward Island | Low[m] | X | X | X | X |
| ESP | | | | | |
| Tuscaloosa | Normal | X | | X | |

(continued)

TABLE C-1. OVERVIEW OF EMISSION DATA BASE (Continued)

| Facility name | Test condition | Criteria pollutants | Acid gases | Metals | Organics |
|---|---|---|---|---|---|
| RDF fired | | | | | |
| ESP | | | | | |
| Akron | Normal | X | X | X | X |
| Albany | Normal | X | X | X | X |
| Hamilton-Wentworth | F/None[n] | X | | | X |
| Hamilton-Wentworth | F/Low back[o] | X | | | X |
| Hamilton-Wentworth | F/Back[p] | X | | | X |
| Hamilton-Wentworth | F/Back, low front[q] | X | | | X |
| Hamilton-Wentworth | H/None[r] | X | | | X |
| Hamilton-Wentworth | H/Low back[s] | X | | | X |
| CYC/ESP | | | | | |
| Wright Pat. AFB | Normal | | | | X |
| Wright Pat. AFB | Dense RDF[t] | | X | | |
| CYC/DI/ESP/FF | | | | | |
| Malmo | RDF[u] | X | X | X | |

[a] Type of incinerator design.

[b] Type of furnace.

[c] Emission control device(s) as follows: CYC = Cyclone; DI = dry sorbent injection; SD = spray dryer; EGB = electrostatic granular bed; ESP = electrostatic precipitator; FF = fabric filter; WS = wet scrubber; and WSH = water spray humidifier.

[d] Unit operated under normal conditions during tests.

[e] Unit burned MSW only during tests.

[f] Gases entering the fabric filter were at the temperature specified in °C.

[g] Normal operations: gases entering the fabric filter were at 140°C and normal lime feed rate was used.

[h] Sorbent recycle was used. Gases entering the fabric filter were at 140°C.

[i] Unit burned MSW and waste oil during tests.

[j] Unit under normal conditions during experimental test program.

[k] Unit operated under longer feed cycle to decrease demand on the tractor operator during tests.

[l] Unit operated with high secondary chamber temperature during tests.

[m] Unit operated with low secondary chamber temperatures during tests.

[n] Unit operated under full load with no overfire air.

[o] Unit operated under full load with only lower back overfire air ports open.

[p] Unit operated under full load with both back overfire air ports open.

[q] Unit operated under full load with both back and lower front overfire air ports open.

[r] Unit operated under half load with no overfire air.

[s] Unit operated under half load with only lower back overfire air ports open.

[t] Unit burned densified RDF during tests.

[u] Unit burned RDF during tests.

## TABLE C-2. OVERVIEW OF SUPPLEMENTARY EMISSION DATA BASE

| Facility name | Test condition | Metals | Organics |
|---|---|---|---|
| Mass burn | | | |
| Waterwall/ESP | | | |
| Avesto | Normal | X | |
| Iserlohn | Normal | | X |
| MVA Lausanne | Normal | X | |
| MVA Munich | Normal | X | |
| Montreal (1982) | Normal | | X |
| Montreal (1983) | Normal | | X |
| Quebec (1981) | Normal | | X |
| Umea (1984) | Normal | | X |
| Umea (1985) | Normal | | X |
| Zurich/Josephstrasse | Normal | | X |
| Waterwall/ESP/DS | | | |
| Hamburg/Stapelfeld | Normal | | X |
| MVA-I Borsigstrasse | Normal | | X |
| MVA-II Stellinger M. | Normal | | X |
| Waterwall/DS/ESP/FF | | | |
| Malmo | Normal | | X |
| Waterwall/DS/FF | | | |
| Avg Borsigstrasse | Normal | | X |
| Waterwall | | | |
| Issy-les-Moulineaux | Normal | X | |
| Saint-ouen | Normal | X | |
| Refractory/SPRAY/ESP | | | |
| Toronto I | Normal | | X |
| Refractory/ESP | | | |
| Brasschaat | Normal | | X |
| Harelbeke | Normal | | X |
| Linkoping | Normal | | X |
| Stuttgart | Normal | | X |
| Zaanstad | Normal | | X |
| Refractory | | | |
| Beveren | Normal | | X |
| Milan I | Normal | | X |
| Milan II | Normal | | X |
| Starved air | | | |
| None | | | |
| Lake Cowichan | Normal | | X |
| CS/ESP | | | |
| Schio | Normal[a] | | X |
| Schio | Unprocessed | | X |
| Fluid bed | | | |
| FF | | | |
| Eskjo | Normal | | X |

[a] Waste separated to produce compost is termed processed. This is the normal operating condition for this facility.

# APPENDIX D

# MUNICIPAL WASTE COMPOSITION

7

## TABLE D-1. ASSUMED MSW COMPOSITION

| Species | Weight Percent |
|---|---|
| Carbon | 26.73 |
| Hydrogen | 3.60 |
| Sulfur | 0.12 |
| Nitrogen | 0.17 |
| Chlorine | 0.12 |
| Ash | 22.38 |
| Oxygen | 19.74 |
| Moisture | 27.14 |
| Higher Heating Value | 4500 Btu/lb. |

# APPENDIX E

# EMISSION CONTROL COST TABLES

## TABLE E-1. SUMMARY OF ESTIMATED CAPITAL COSTS OF EMISSION CONTROL SYSTEMS FOR NEW MODEL MUNICIPAL WASTE COMBUSTOR FACILITIES[a]

($1,000s in August 1986 based on 8,000 hrs/yr operation)

| PM emission level after control, gr/dscf at 12% $CO_2$ | Mass burning model facilities | | | Modular model facilities | | | Refuse-derived fuel model facilities | |
|---|---|---|---|---|---|---|---|---|
| | 250 tpd capacity (Model No. 1) | 1,000 tpd capacity (Model No. 2) | 3,000 tpd capacity (Model No. 3) | 100 tpd capacity (Model No. 4) | 250 tpd capacity (Model No. 5) | 400 tpd capacity (Model No. 6) | 1,500 tpd capacity (Model No. 7) | 3,000 tpd capacity (Model No. 8) |
| ESP System | | | | | | | | |
| 0.03 | 1,549 | 3,900 | 10,230 | 341 | 695 | 1,020 | 6,919 | 12,006 |
| 0.02 | 1,951 | 4,693 | 11,830 | 447 | 845 | 1,194 | 8,293 | 14,245 |
| 0.01 | 2,252 | 5,521 | 14,105 | 487 | 929 | 1,314 | 9,193 | 15,881 |
| Spray Dryer/ ESP System[b] | | | | | | | | |
| 0.03 | 4,108 | 9,352 | 23,197 | 1,426 | 2,420 | 3,149 | 14,413 | 25,917 |
| 0.02 | 4,589 | 10,246 | 24,488 | 1,516 | 2,526 | 3,489 | 15,972 | 27,423 |
| 0.01 | 4,868 | 10,916 | 26,641 | 1,564 | 2,648 | 3,609 | 16,539 | 28,069 |
| Spray Dryer/ FF System[b] | | | | | | | | |
| 0.03 | 4,242 | 8,905 | 21,691 | 1,960 | 3,176 | 4,179 | 13,170 | 22,042 |
| 0.02 | 4,242 | 8,905 | 21,691 | 1,960 | 3,176 | 4,179 | 13,170 | 22,402 |
| 0.01 | 4,421 | 9,463 | 23,197 | 2,020 | 3,296 | 4,779 | 13,989 | 23,119 |

---

[a] The capital cost estimates were developed for control systems at 125 percent of actual size and include a 20 percent contingency factor.

[b] Spray dryer designed for 90 and 70 percent control of HCl and $SO_2$, respectively.

## TABLE E-2. SUMMARY OF ESTIMATED ANNUALIZED OPERATING COSTS OF EMISSION CONTROL SYSTEMS FOR NEW MODEL MUNICIPAL WASTE COMBUSTOR FACILITIES ($1,000s in August 1986 based on 8,000 hrs/yr operation)

| PM emission level after control, gr/dscf at 12% $CO_2$ | Mass burning model facilities | | | Modular model facilities | | | Refuse-derived fuel model facilities | |
|---|---|---|---|---|---|---|---|---|
| | 250 tpd capacity (Model No. 1) | 1,000 tpd capacity (Model No. 2) | 3,000 tpd capacity (Model No. 3) | 100 tpd capacity (Model No. 4) | 250 tpd capacity (Model No. 5) | 400 tpd capacity (Model No. 6) | 1000 tpd capacity (Model No. 7) | 3,000 tpd capacity (Model No. 8) |
| **ESP System** | | | | | | | | |
| 0.03 | 370 | 921 | 2,449 | 90 | 162 | 229 | 1,865 | 3,348 |
| 0.02 | 443 | 1.067 | 2,744 | 110 | 190 | 261 | 2,118 | 3,761 |
| 0.01 | 499 | 1.220 | 3,163 | 117 | 206 | 283 | 2,284 | 4,063 |
| **Spray Dryer/ ESP System**[a] | | | | | | | | |
| 0.03 | 1.061 | 2,529 | 6,515 | 380 | 645 | 858 | 4,278 | 7,876 |
| 0.02 | 1.156 | 2,706 | 6,771 | 398 | 666 | 925 | 4,632 | 8,176 |
| 0.01 | 1.212 | 2,839 | 7,198 | 408 | 691 | 949 | 4,700 | 8,305 |
| **Spray Dryer/ FE System**[a] | | | | | | | | |
| 0.03 | 1.115 | 2,549 | 6,538 | 498 | 825 | 1.110 | 4,198 | 7,442 |
| 0.02 | 1.115 | 2,549 | 6,540 | 498 | 825 | 1.110 | 4,199 | 7,444 |
| 0.01 | 1.150 | 2,661 | 6,838 | 510 | 849 | 1.229 | 4,362 | 7,637 |

---

[a] Spray dryer designed for 90 and 70 percent control of HCl and $SO_2$, respectively.

TABLE E-3. SUMMARY OF ESTIMATED CAPITAL COSTS OF EMISSION CONTROL SYSTEMS FOR EXISTING MODEL REFRACTORY MUNICIPAL WASTE COMBUSTOR FACILITIES
($1000s in August 1986 based on 6,500 hrs/yr operation)

| | Mass Burn | | | | | Modular |
|---|---|---|---|---|---|---|
| Control Device | 200 tpd capacity (Model No. 1) | 450 tpd capacity (Model No. 2) | 600 tpd capacity (Model No. 3) | 750 tpd capacity (Model No. 4) | 1200 tpd capacity (Model No. 5) | 100 tpd capacity Model No. 6) |
| ESP System[a] | | | | | | 526 |
| Dry Scrubber System [b] | | | 6,005 | 6,879 | 10,325 | |
| Dry Scrubber/ESP System [a,b] | | | | | | 2,819 |
| Dry Scrubber/Fabric Filter System [a,b] | 6,335 | 11,346 | 11,062 | 12,728 | 18,745 | |

[a] 0.02 gr/dscf corrected to 12 percent $CO_2$.

[b] 90 and 70 percent reduction of HCl and $SO_2$, respectively.

## TABLE E-4. SUMMARY OF ESTIMATED ANNUALIZED OPERATING COSTS OF EMISSION CONTROL SYSTEMS FOR EXISTING MODEL REFRACTORY MUNICIPAL WASTE COMBUSTOR FACILITIES
($1000s in August 1986 based on 6,500 hrs/yr operation)

| | Mass Burn | | | | | Modular |
|---|---|---|---|---|---|---|
| Control Device | 200 tons/day capacity (Model No. 1) | 450 tons/day capacity (Model No. 2) | 600 tons/day capacity (Model No. 3) | 750 tons/day capacity (Model No. 4) | 1200 tons/day capacity (Model No. 5) | 100 tons/day capacity (Model No. 6) |
| Esp System[a] | | | | | | 123 |
| Dry Scrubber System [b] | | | 1,669 | 1,941 | 2,884 | |
| Dry Scrubber/ESP System [a,b] | | | | | | 645 |
| Dry Scrubber/Fabric Filter System [a,b] | 1,478 | 2,686 | 2,692 | 3,124 | 4,597 | |

[a] 0.02 gr/dscf corrected to 12 percent $CO_2$.

[b] 90 and 70 percent reduction of HCl and $SO_2$, respectively.

## TABLE E-5. SUMMARY OF ESTIMATED CAPITAL COSTS OF EMISSION CONTROL SYSTEMS FOR MODEL EXISTING WATERWALL MUNICIPAL WASTE COMBUSTOR FACILITIES

($1000s in August 1986 based on 6,500 hrs/yr operation)

| | Mass Burn | | | | Modular | | | RDF | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Control Device | 200 tpd capacity (Model No.1) | 400 tpd capacity (Model No.2) | 1000 tpd capacity (Model No.3) | 2200 tpd capacity (Model No.4) | 100 tpd capacity (Model No.5) | 200 tpd capacity (Model No.6) | 300 tpd capacity (Model No.7) | 1000 tpd capacity (Model No.8) | 2200 tpd capacity (Model No.9) | 3000 tpd capacity (Model No.10) |
| ESP System[a] | | | | | 487 | 783 | 999 | | | |
| Dry Scrubber System[b] | 3,063 | 4,544 | 9,901 | 14,353 | | | | 10,202 | 12,926 | 19,492 |
| Dry Scrubber ESP System[a,b] | | | | | 2,551 | 3,853 | 4,865 | | | |
| Dry Scrubber/ Fabric Filter System[a,b] | 5,997 | 8,539 | 18,690 | 25,307 | | | | 19,189 | 22,090 | 34,058 |

[a] 0.02 gr/dscf corrected to 12 percent $CO_2$.

[b] 90 and 70 percent reduction of HCl and $SO_2$, respectively.

## TABLE E-6. SUMMARY OF ESTIMATED ANNUALIZED OPERATING COSTS OF EMISSION CONTROL SYSTEMS FOR MODEL EXISTING WATERWALL MUNICIPAL WASTE COMBUSTOR FACILITIES

($1000s in August 1986 based on 6,500 hrs/yr operation)

| | Mass Burn | | | | Modular | | | RDF | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Control Device | 200 tpd capacity (Model No.1) | 400 tpd capacity (Model No.2) | 1000 tpd capacity (Model No.3) | 2200 tpd capacity (Model No.4) | 100 tpd capacity (Model No.5) | 200 tpd capacity (Model No.6) | 300 tpd capacity (Model No.7) | 1000 tpd capacity (Model No.8) | 2200 tpd capacity (Model No.9) | 3000 tpd capacity (Model No.10) |
| ESP System[a] | | | | | 115 | 177 | 224 | | | |
| Dry Scrubber System[b] | 810 | 1,222 | 2,724 | 4,278 | | | | 3,067 | 4,574 | 6,350 |
| Dry Scrubber/ ESP System[a,b] | | | | | 578 | | 1,124 | | | |
| Dry Scrubber/ Fabric Filter System[a,b] | 1,399 | 2,030 | 4,506 | 6,543 | | | | 4,876 | 6,458 | 9,558 |

[a] 0.02 gr/dscf corrected to 12 percent $CO_2$.

[b] 90 and 70 percent reduction of HCl and $SO_2$, respectively.

# APPENDIX F

# SUMMARY OF SYMBOLS, ACRONYMS, AND ABBREVIATIONS

## TABLE F-1. SUMMARY OF SYMBOLS, ACRONYMS, AND ABBREVIATIONS

| Symbol | Meaning |
|---|---|
| As | Arsenic |
| BaP | Benzo(a)pyrene |
| Be | Beryllium |
| Cd | Cadmium |
| CDD | Chlorinated dibenzo-para-dioxins |
| CDF | Chlorinated dibenzo furans |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| Cr | Chromium |
| ESP | Electrostatic precipitator |
| HCl | Hydrogen chloride |
| HF | Hydrogen fluoride |
| Hg | Mercury |
| Ni | Nickel |
| $NO_x$ | Nitrogen oxides |
| NSPS | New source performance standards |
| $O_2$ | Oxygen |
| Pb | Lead |
| PCB | Polychlorinated biphenyl |
| PCDD | Polychlorinated dibenzo-p-dioxins |

TABLE F-1. SUMMARY OF SYMBOLS, ACRONYMS, AND ABBREVIATIONS (Continued)

| | |
|---|---|
| PCDF | Polychlorinated dibenzofurans |
| ppb | Parts per billion |
| RfD | Risk Reference Dose |
| RDF | Refuse-derived fuel |
| SASS | Source assessment sampling system |
| SCR | Selective catalytic reduction |
| $SO_2$ | Sulfur dioxide |
| TCDD | Tetrachlorodibenzo-p-dioxins |
| TEF | Toxic equivalency factor |
| TCDF | Tetrachlorodibenzofurans |
| TPD | Tons per day |

# APPENDIX G

# LIST OF CONVERSION FACTORS

## TABLE G-1. LIST OF CONVERSION FACTORS

| Multiply | By | To obtain |
|---|---|---|
| $mg/Nm^3$ [a] | $4.37 \times 10^{-4}$ | gr/dscf[b] |
| $m^2$ | 10.764 | $ft^2$ |
| $m^3$/min | 35.31 | $ft^3$/min |
| m/s | 3.281 | ft/s |
| kg/h | 2.205 | lb/h |
| kPa | 4.0 | in. of $H_2O$ |
| lpm | 0.264 | gal/min |
| kg/Mg | 2.0 | lb/ton |

Temperature conversion equations

$$^{0}F = (9/5)*^{0}C + 32$$

$$^{0}C = (5/9)*(^{0}F - 32)$$

---

[a] Normal conditions on a dry basis are 1 atm and 20°C.

[b] Dry standard conditions are 1 atm and 68°C.